11th Overset Grid Symposium
October 15th-18th, 2012
Dayton, Ohio, USA

Common Aerospace Applications at DLR Utilizing the Overset Grid Capabilites of DLR’s CFD Codes

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DLR

Outline

- Methodology
  - DLR's solvers w/ overset grid capabilities
  - Our hole-cutting approaches
  - Chimera wall projection
  - Load integration
- Applications
  - CFD-6DoF
  - CROR
  - Helicopters
  - Control surface motion
  - Local discretisation improvement
  - Code-to-code coupling

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Methodology

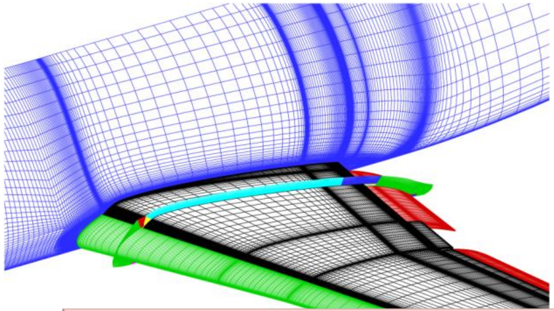
DLR's CFD Solvers w/ Overset Grid Capabilities

Common to both solvers:

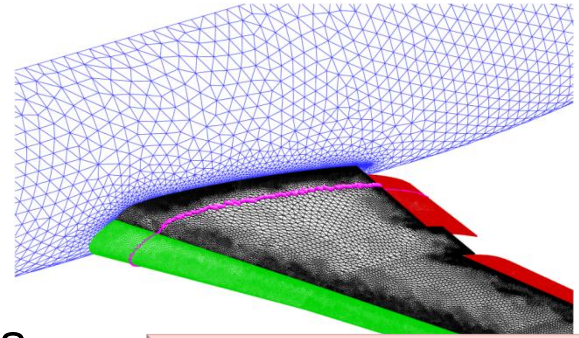
- Developments started in mid 1990s
- FV, 2nd order accuray in space & time
- ALE capability
- Moving, deforming meshes
- Turbulence models: 1-eqn. SA variants, 2-eqn. k-ω-type models, EARSM, RSM; DES, LES
- Fluxes: Central+scalar/matrix diss., Upwinding
- Steady time int.: RK (FLOWer/TAU), LU-SGS, line-implicit (TAU) + multigrid
- Unsteady time int.: Dual-time stepping
- Hybrid MPI/OpenMP-based parallelisation

Special to TAU:

- Work horse of Airbus for aerodynamics analysis on unstructured meshes
- Python interfaces => scripting, in-memory data exchange (6DoF, CFD-CSM coupl.)
- Feature & adjoint-based adaptation



Multiblock-structured compressible RANS solver ***FLOWer***



Unstructured compressible RANS solver ***TAU***

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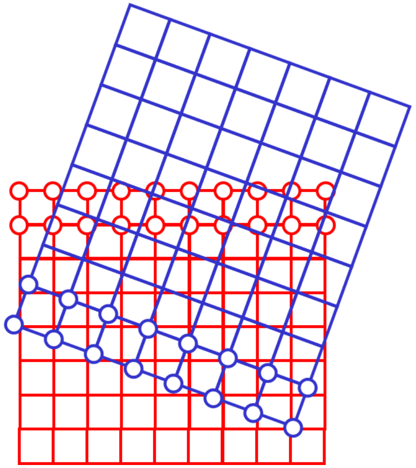
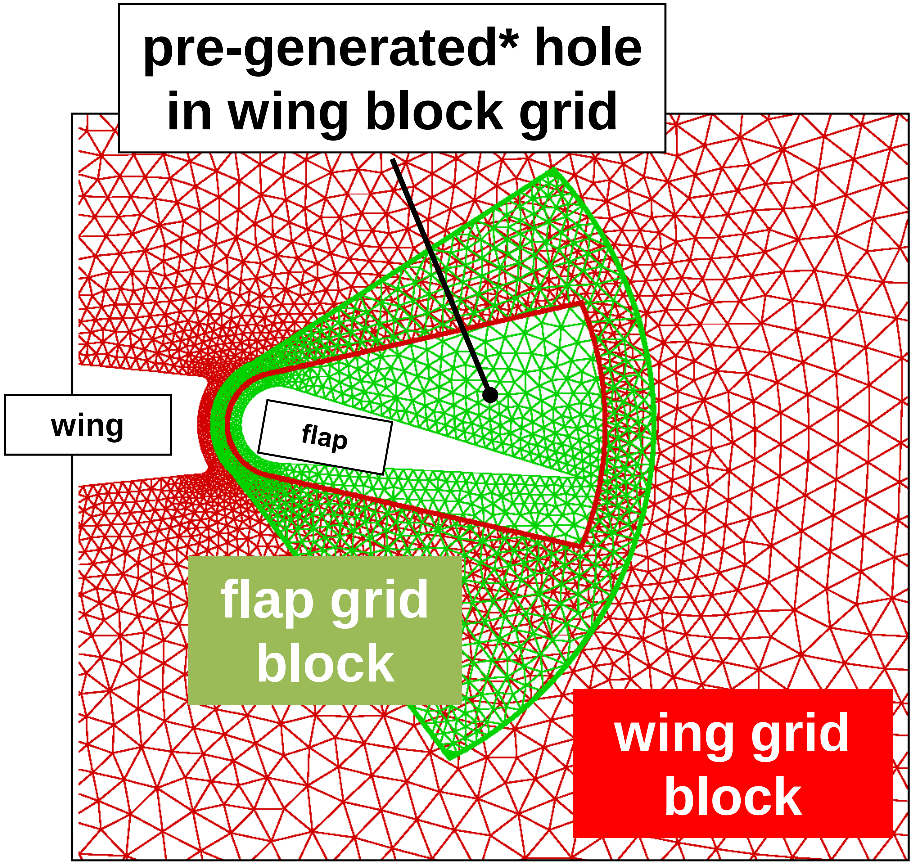
Our Overset Grid Interpolation Technique

- Parallel donor search integrated directly in solver loop (no external tool, no file I/O); 2-stage search
  1. ADT-based search
  2. Iso-parametric mapping based search
- Interpolation is based on primary mesh cells using FE shape functions
  - Only 4 different FE shape functions need to be considered
  - Dual mesh contains arbitrary polyhedrons which would make interpolation more complex & expensive
- Interpolation takes place only on finest multigrid level
- 2 fringe layers

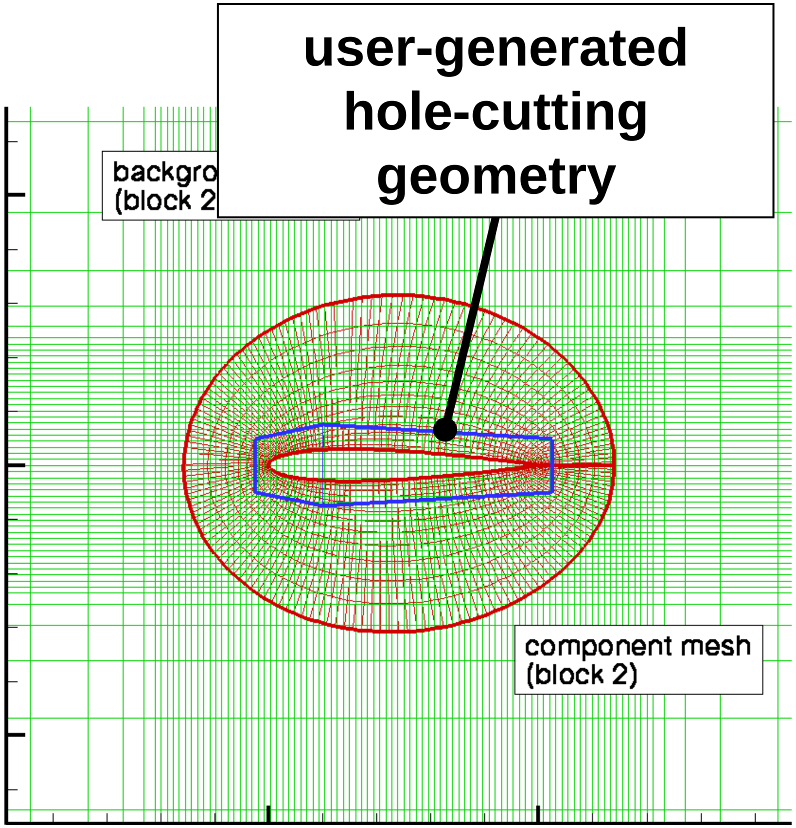


Our Hole-Cutting Strategies

NO hole-cutting



Semi-automatic hole-cutting



*generated during mesh generation

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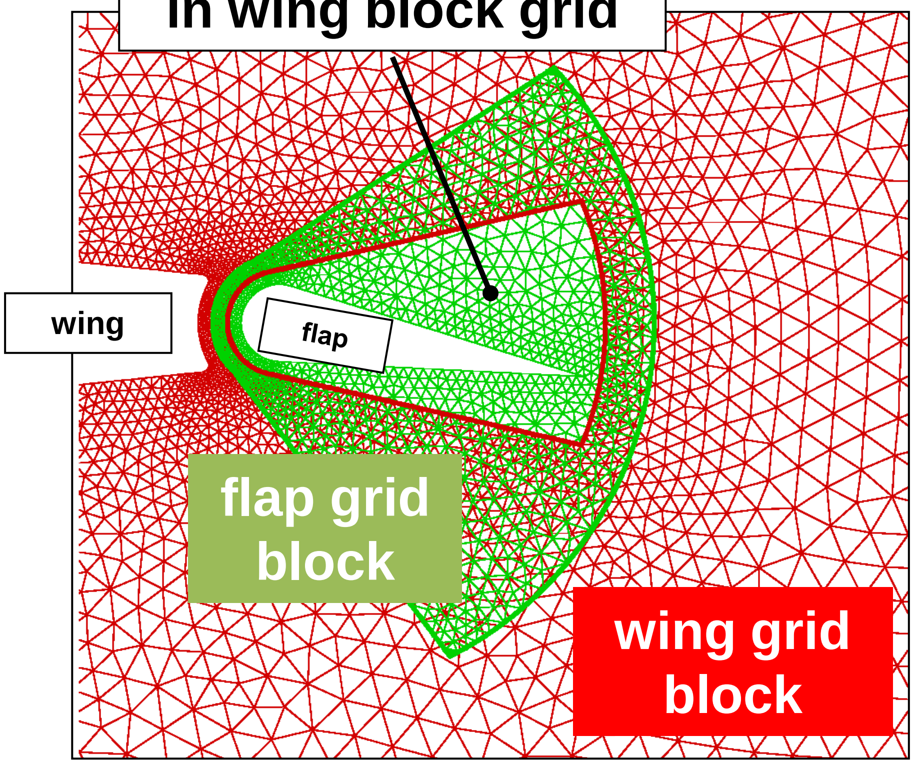

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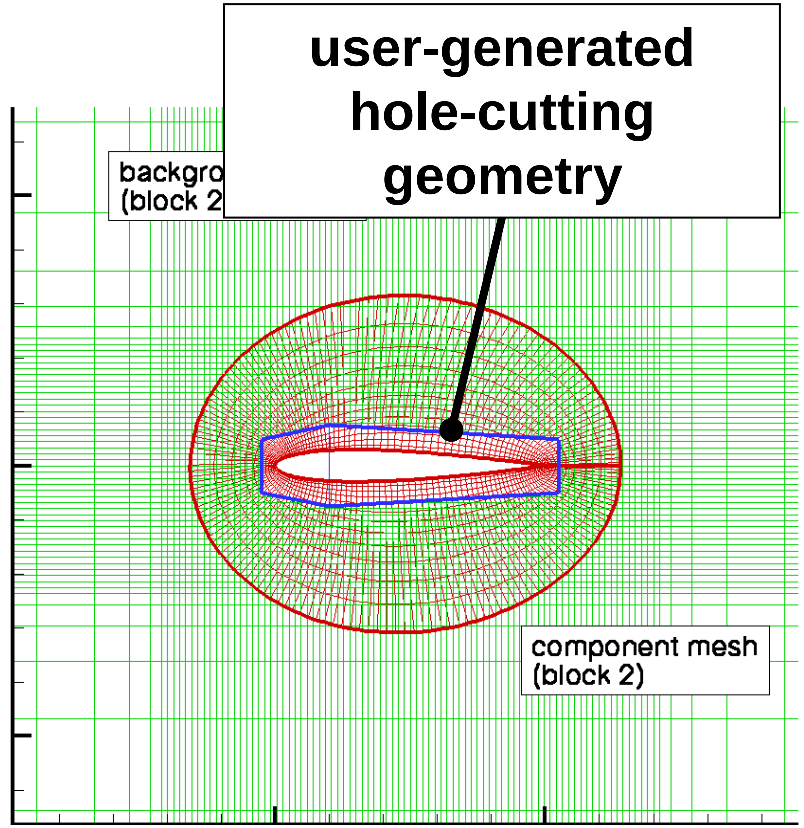

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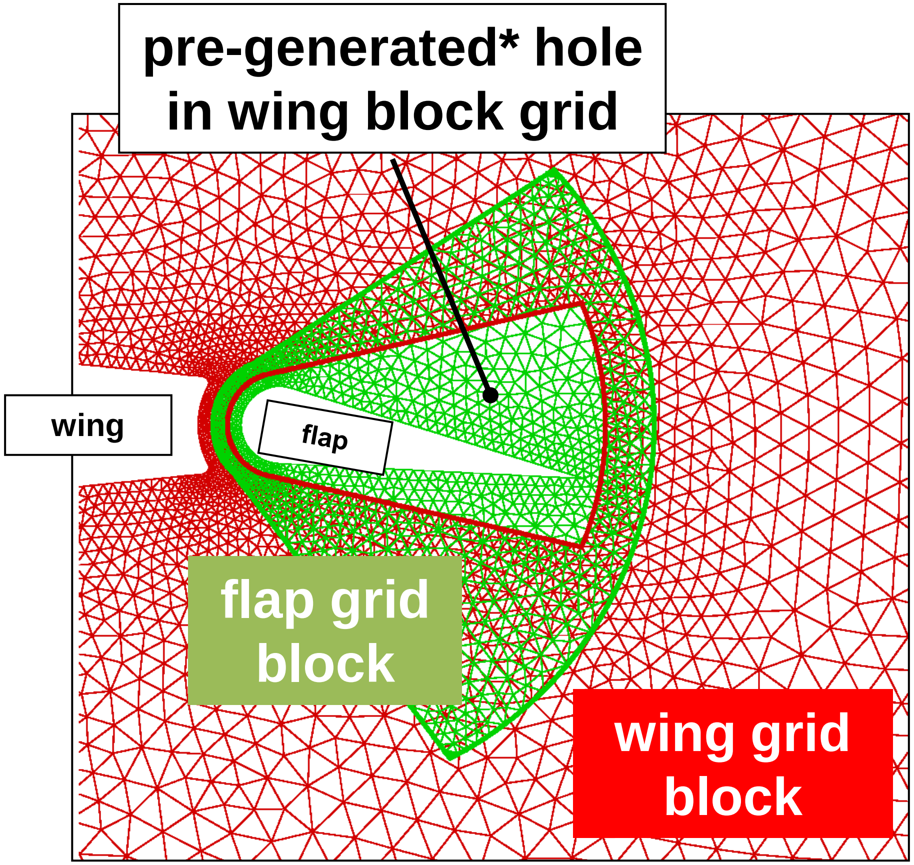

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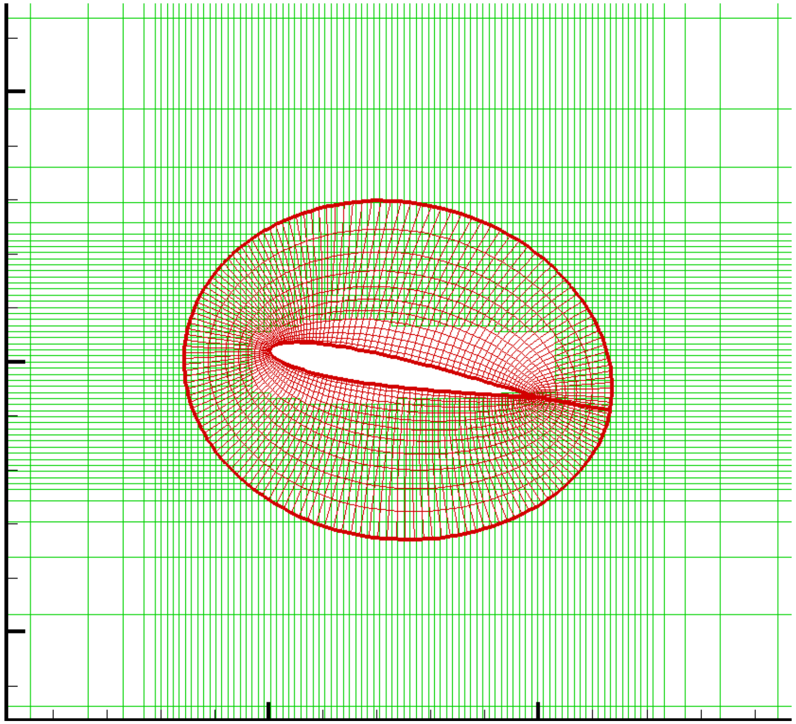

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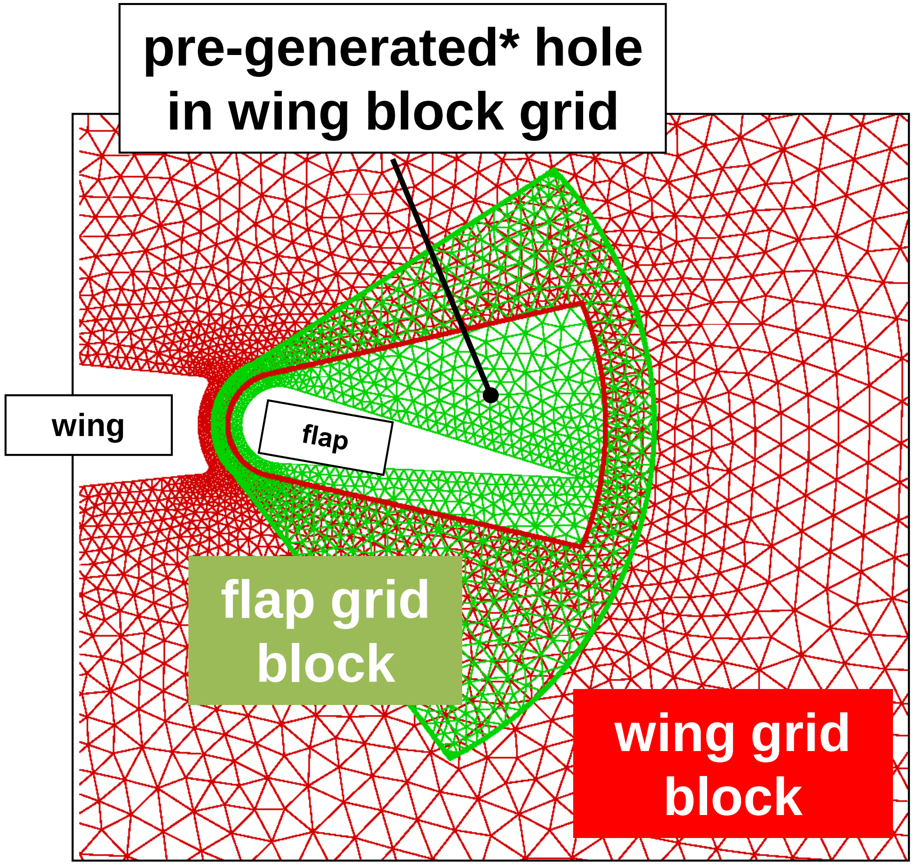

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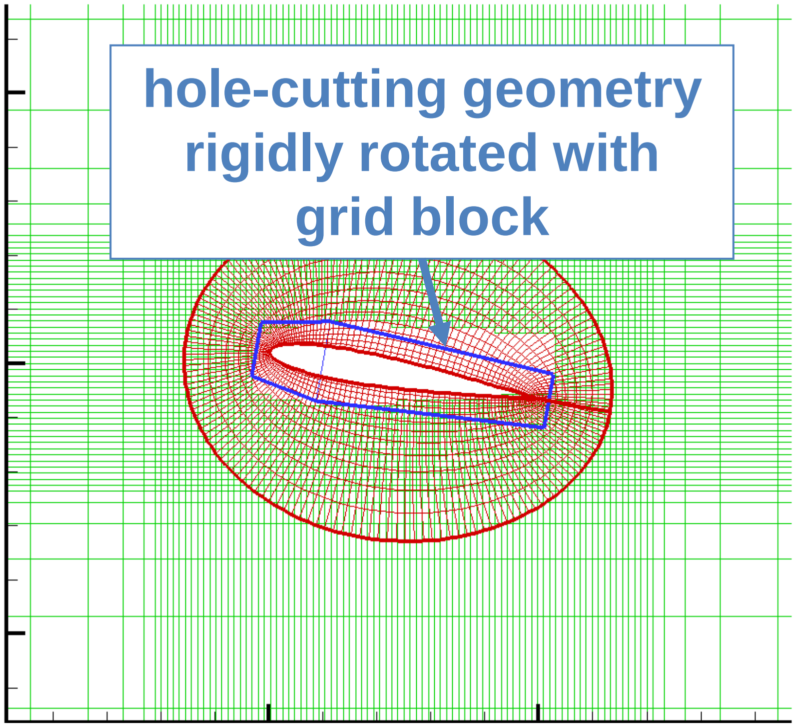

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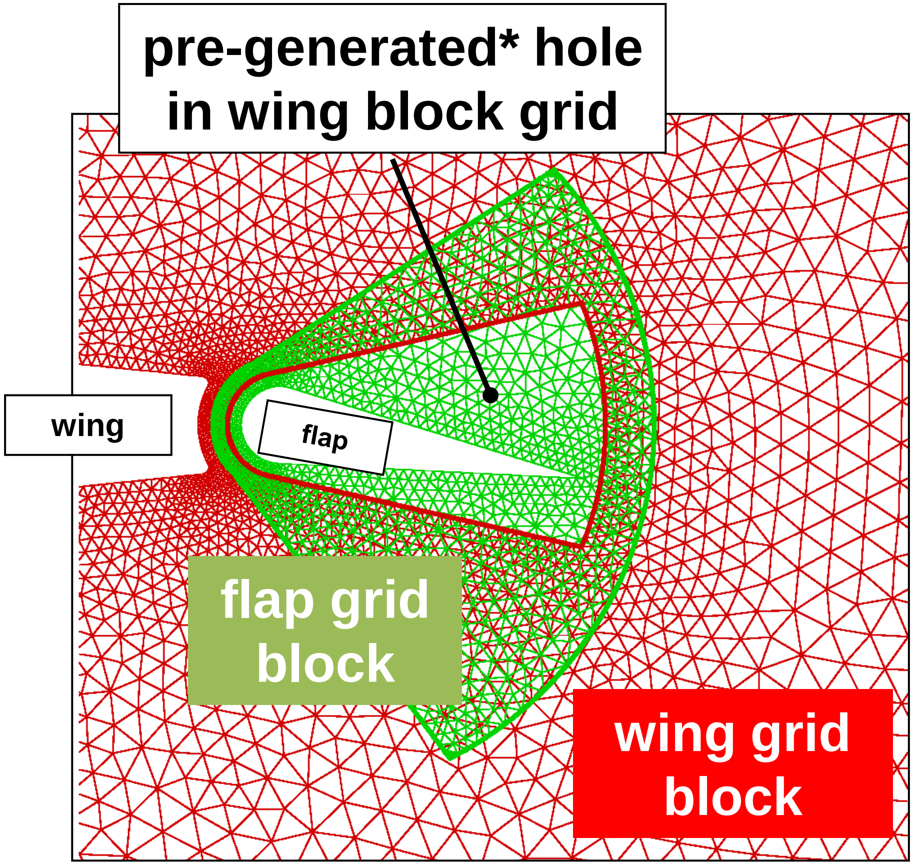

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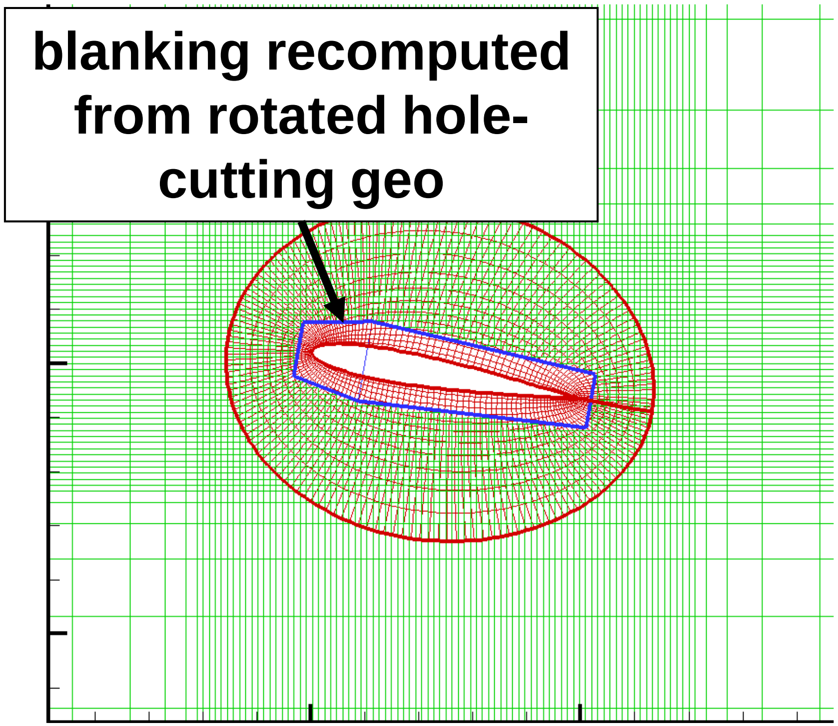

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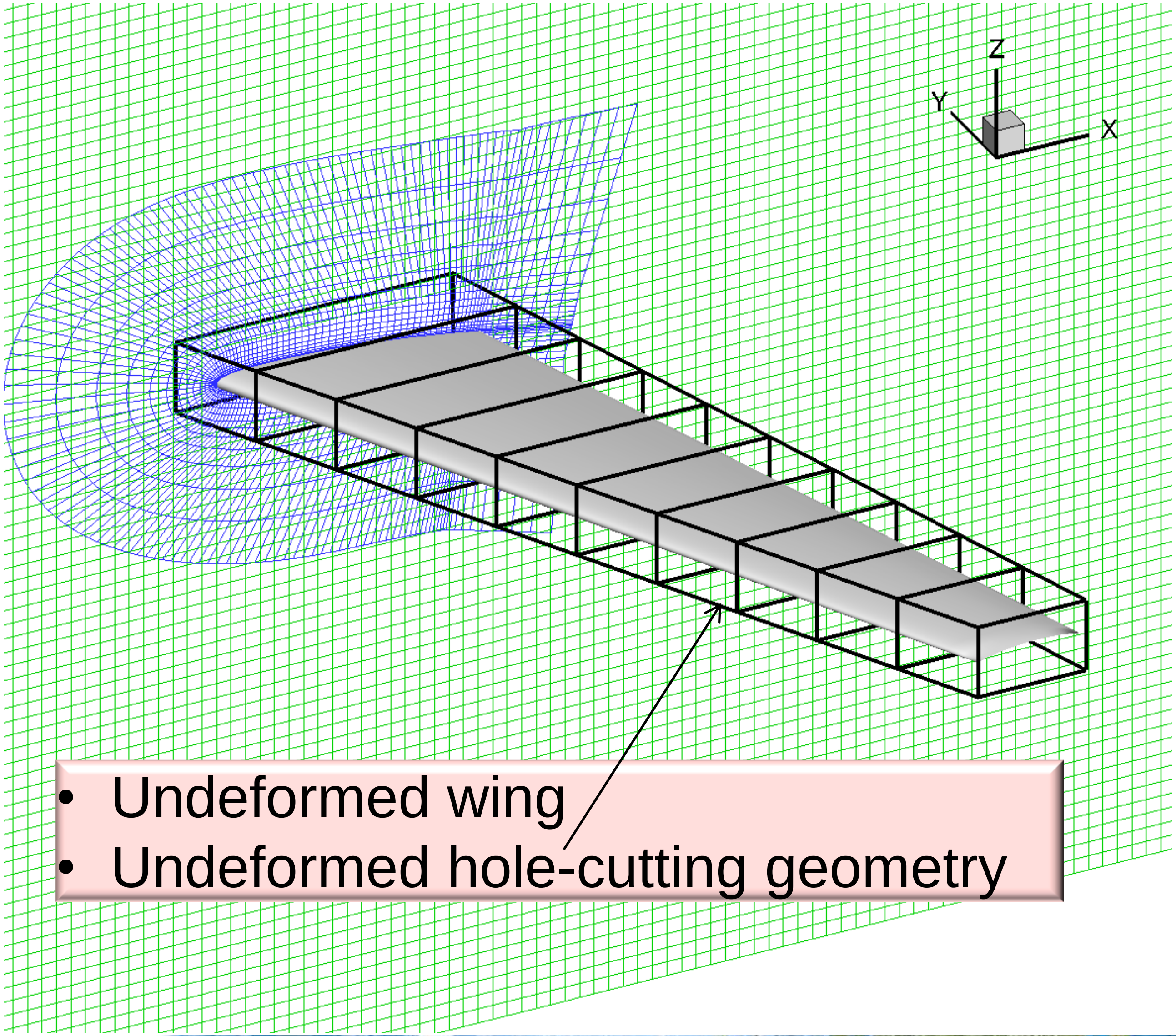
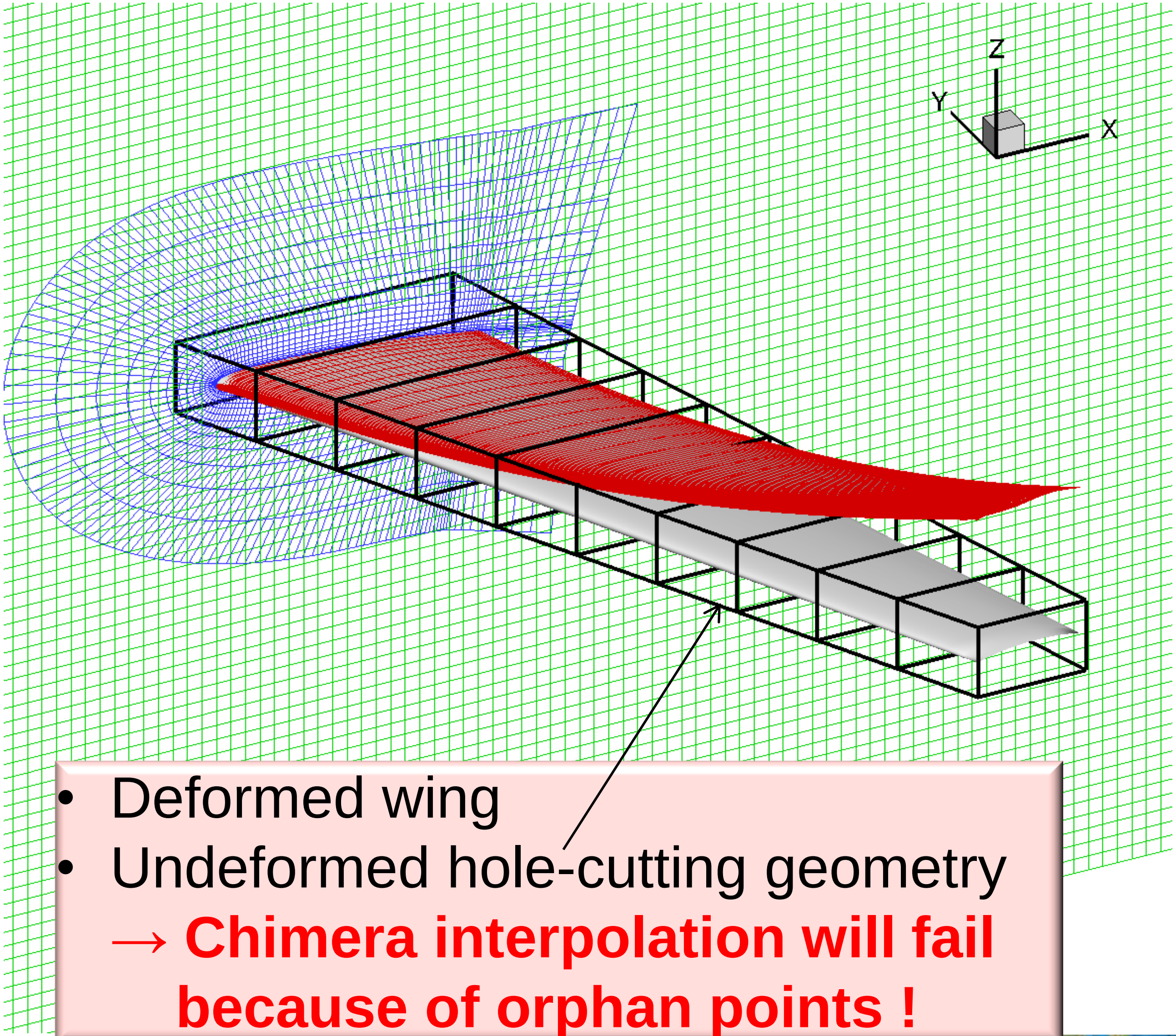
Hole-Cutting Geometries & Mesh Deformation ?



- Undeformed wing
- Undeformed hole-cutting geometry

Hole-Cutting Geometries & Mesh Deformation ?

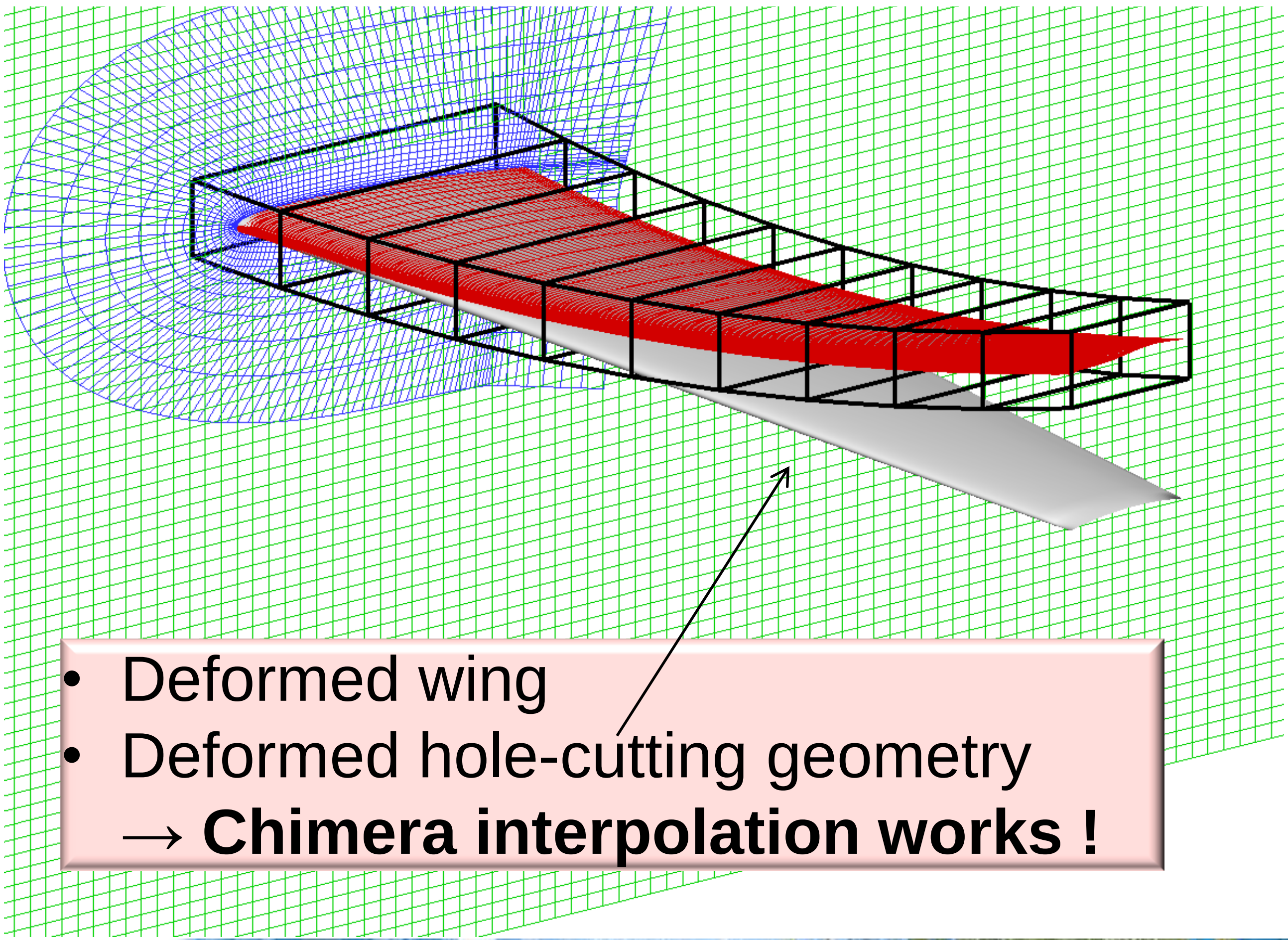


- Deformed wing
- Undeformed hole-cutting geometry

→ Chimera interpolation will fail because of orphan points !

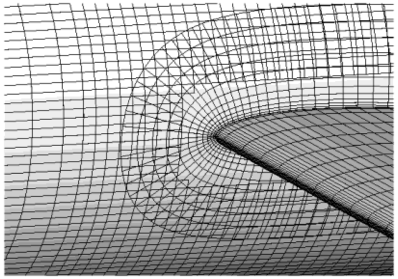
Hole-Cutting Geometries & Mesh Deformation ?

Solution: Mesh deformation operator used for overset grids is also to be applied to hole-cutting geometries

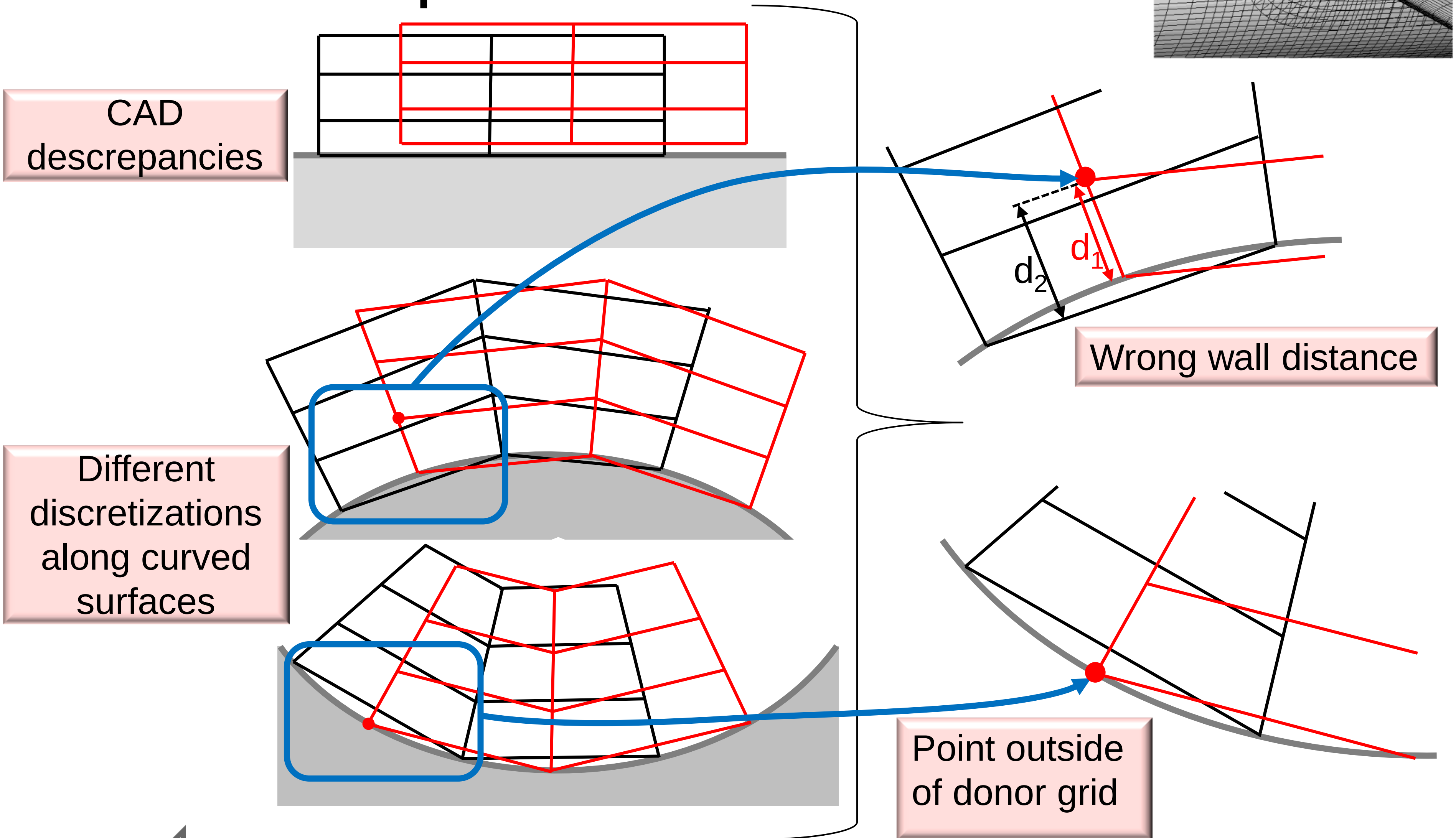


- Deformed wing
- Deformed hole-cutting geometry

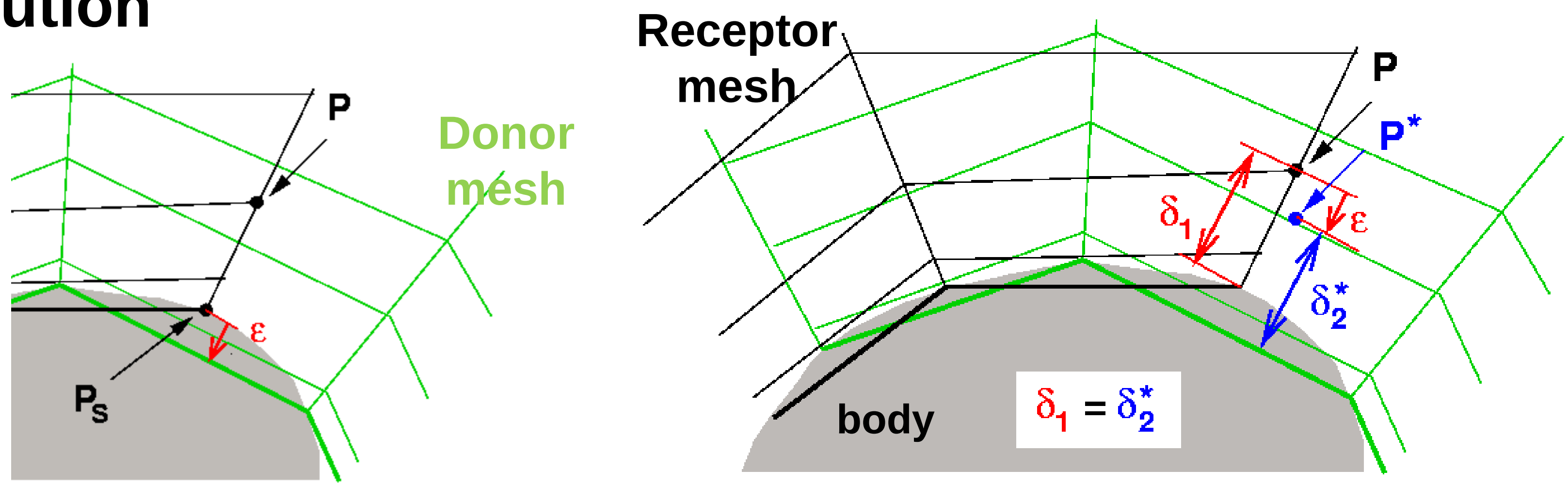
  → **Chimera interpolation works !**



Overlapping Surface Meshes:
Problem Description



Overlapping Surface Meshes:
Solution



A projection method is used, to bypass the problem:

Step 1) Project P to surface of black mesh $\Rightarrow$ point P_S

Step 2) Project Ps in green mesh: $\Rightarrow$ shift vector ε

Step 3) Compute virtual interpolation node P*

$P^* = P + w \cdot \varepsilon$; $w = w(\delta_1)$: Weighting function,

$\delta_1 = 0 : w = 0$; $\delta_1 >> 0 : w = 1$

For interpolation nodes P, P* : $\delta_1 = \delta_2^*$ (with $w = 1$)

<u>Virtual</u> interpolation node enables accurate interpolation

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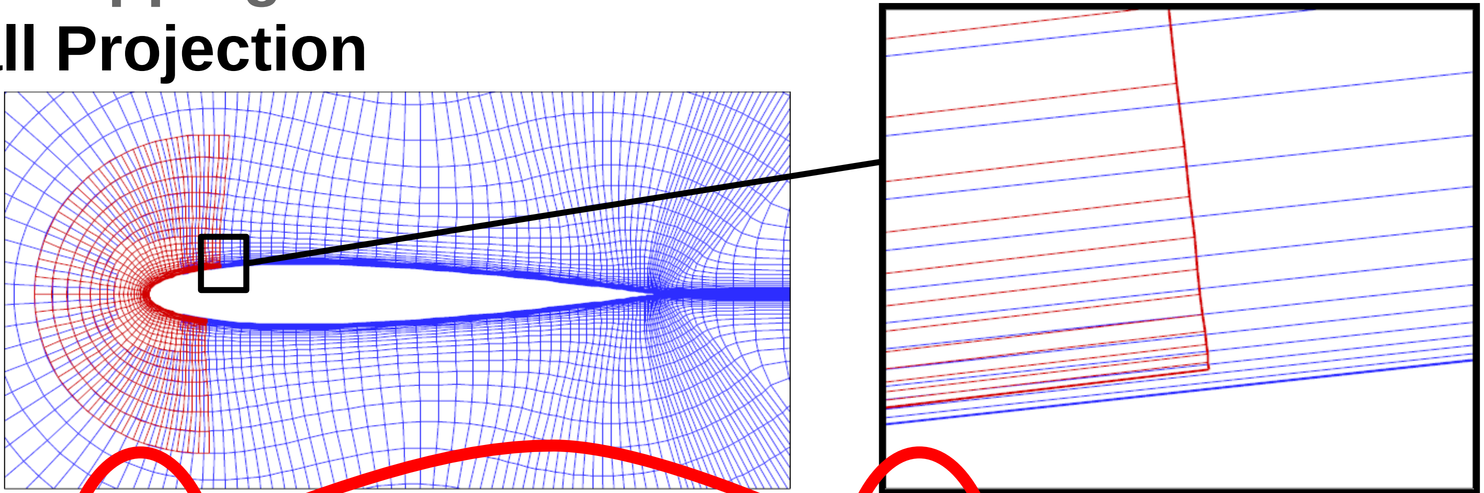
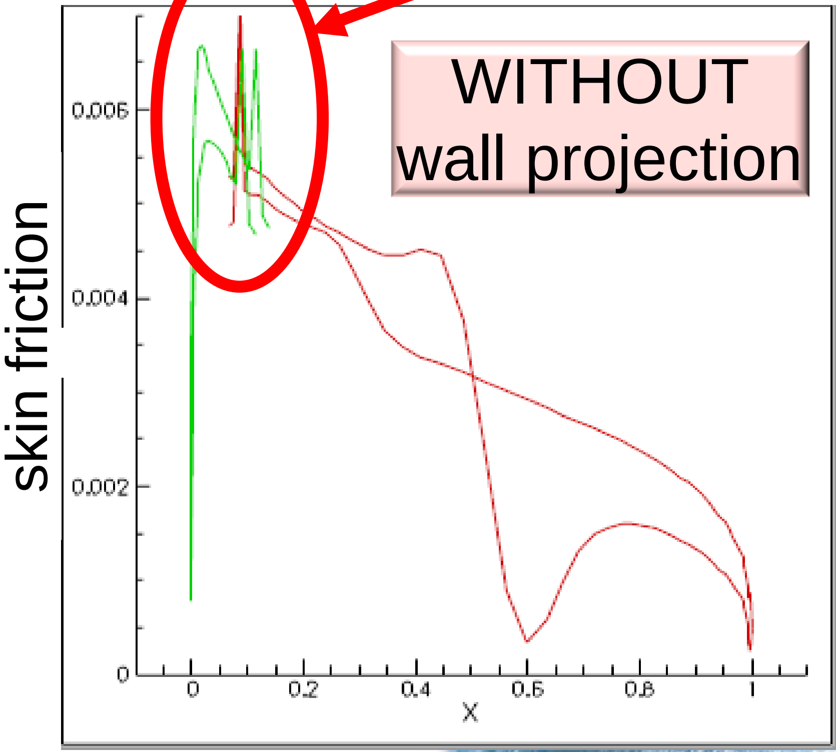
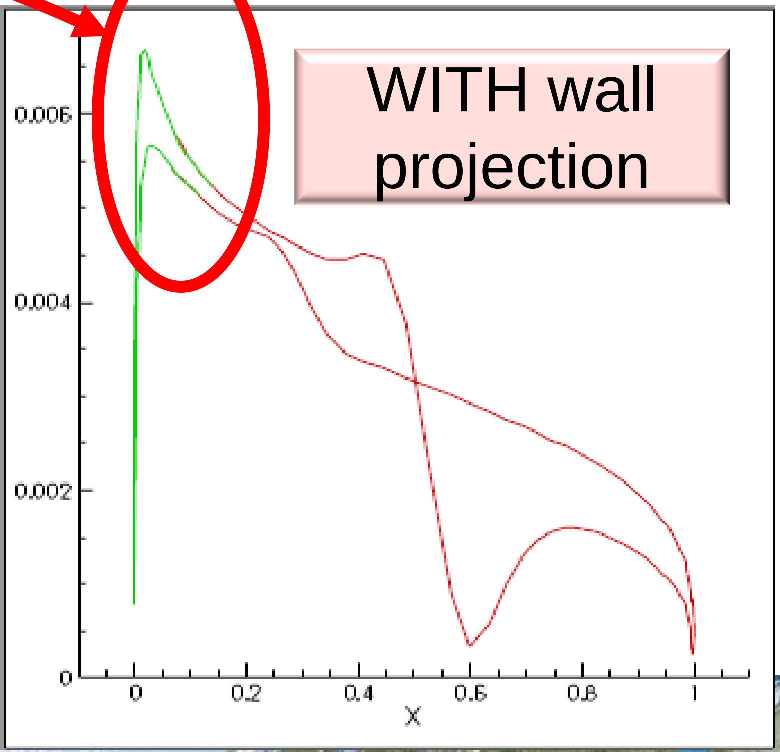
Overlapping Surface Meshes: Results w/ & w/o Chimera

Wall Projection

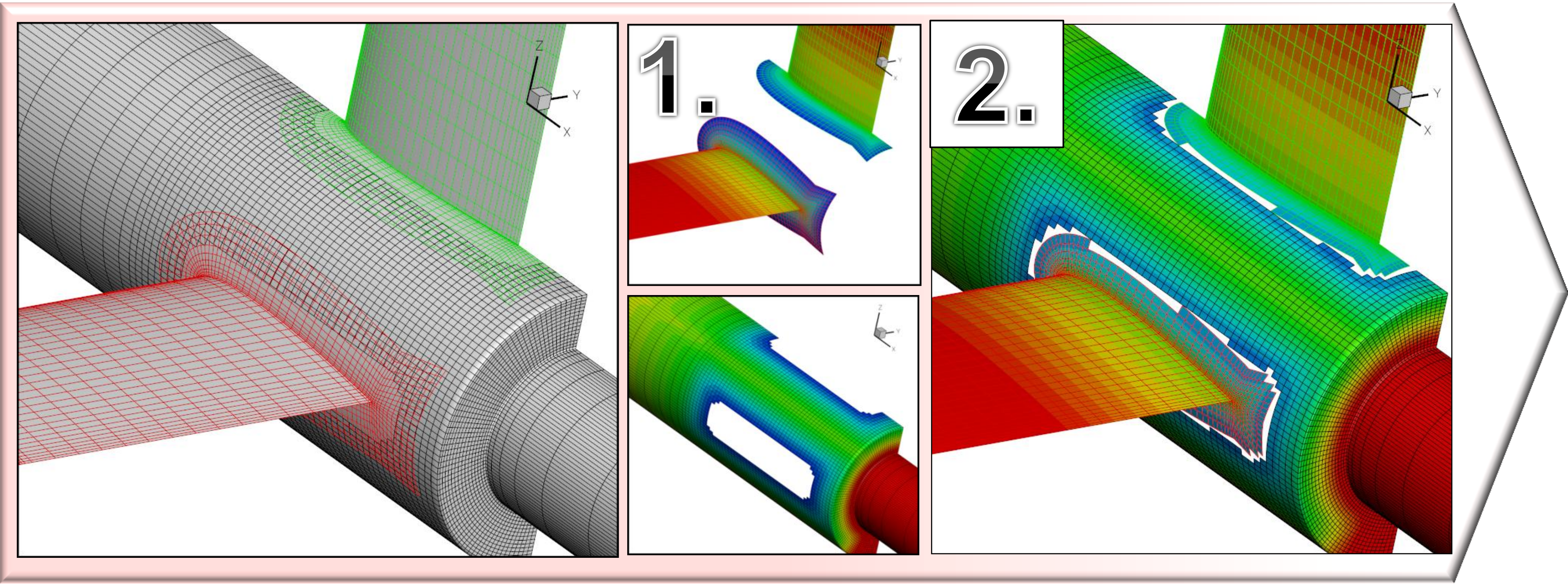






Load Integration on Overlapping Surface Meshes

Problem: Double-counting of cells in regions with overlapping surface grids
=> wrong integral loads



Task: Create an air-tight surface grid , i.e. remove overlap and
fill resulting gaps by triangulation – ***zipper* grids**

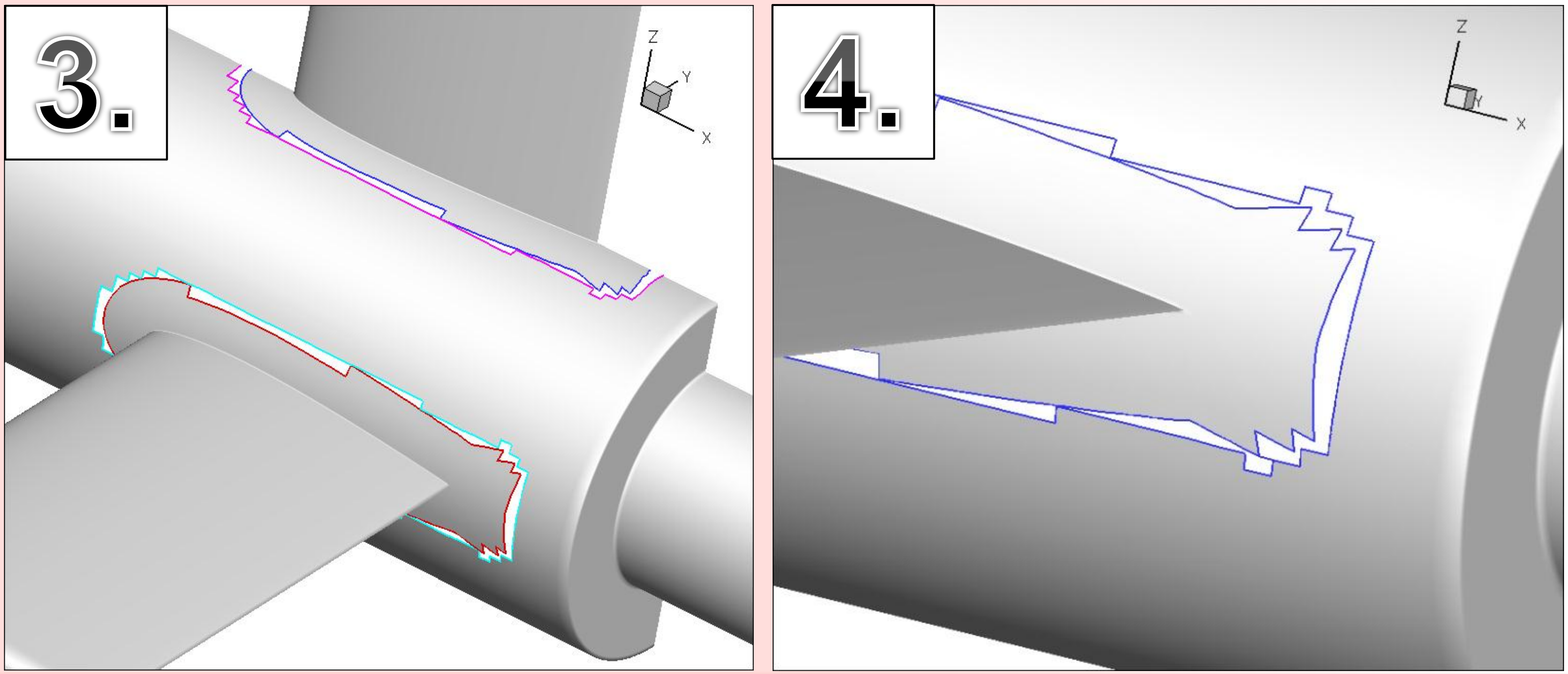
Step 1) Mark cells by distance to Chimera interpolation layer

Step 2) Remove overlapping cells with low priority

=> Overlapping removed , gap has same distance to both interpolation layers

Load Integration on Overlapping Surface Meshes

Problem: Double-counting of cells in regions with overlapping surface grids
=> wrong integral loads



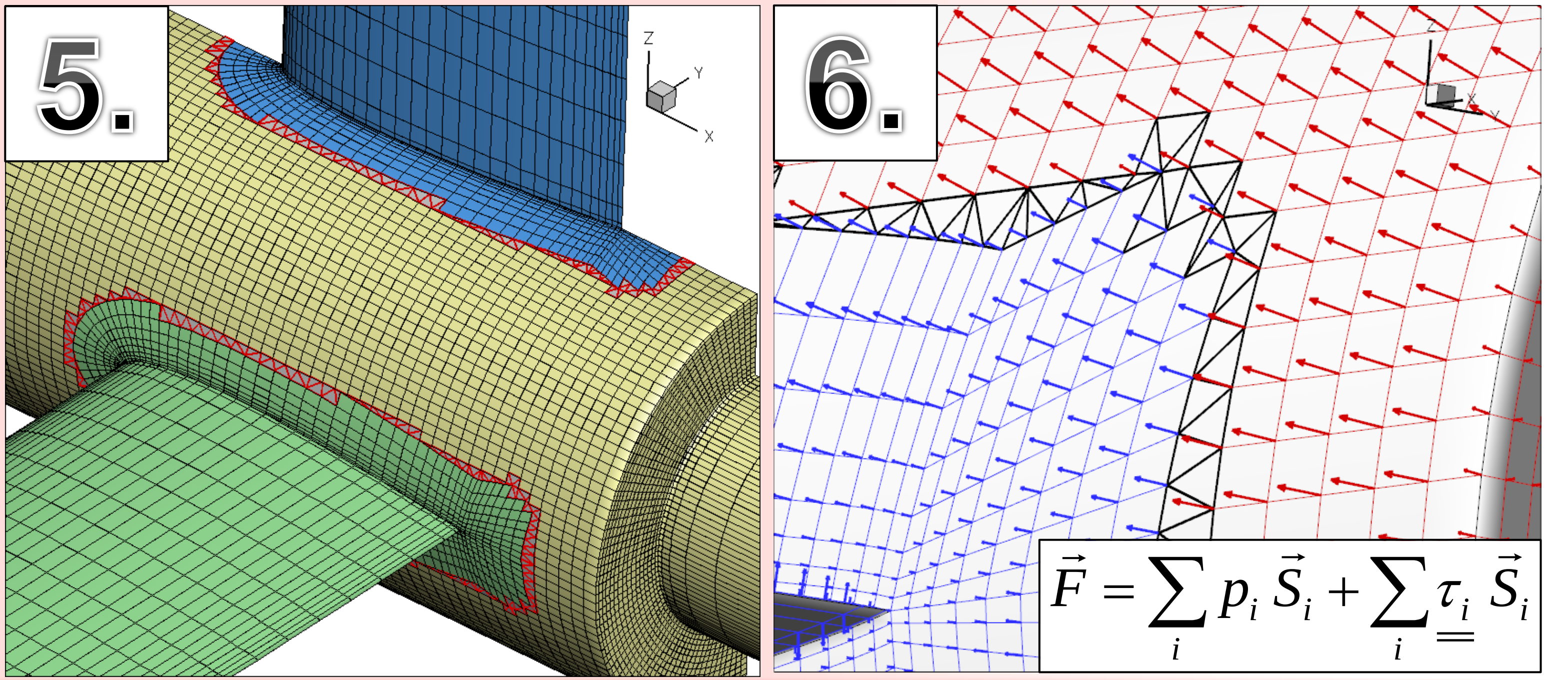
Task: Create a air-tight surface grid = Remove overlap and fill gaps by triangulation – **zipper grids**

Step 3) Extract border lines of resulting grids

Step 4) Gather opposing border lines to build gap data that is to be triangulated

Load Integration on Overlapping Surface Meshes

Problem: Double-counting of cells in regions with overlapping surface grids
=> wrong integral loads



Task: Create a air-tight surface grid = Remove overlap and fill gaps by triangulation – **zipper grids**

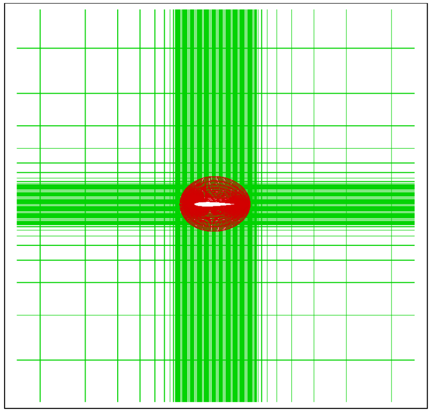
Step 5) Delaunay triangulation

Step 6) Force summation on non-overlapping grid

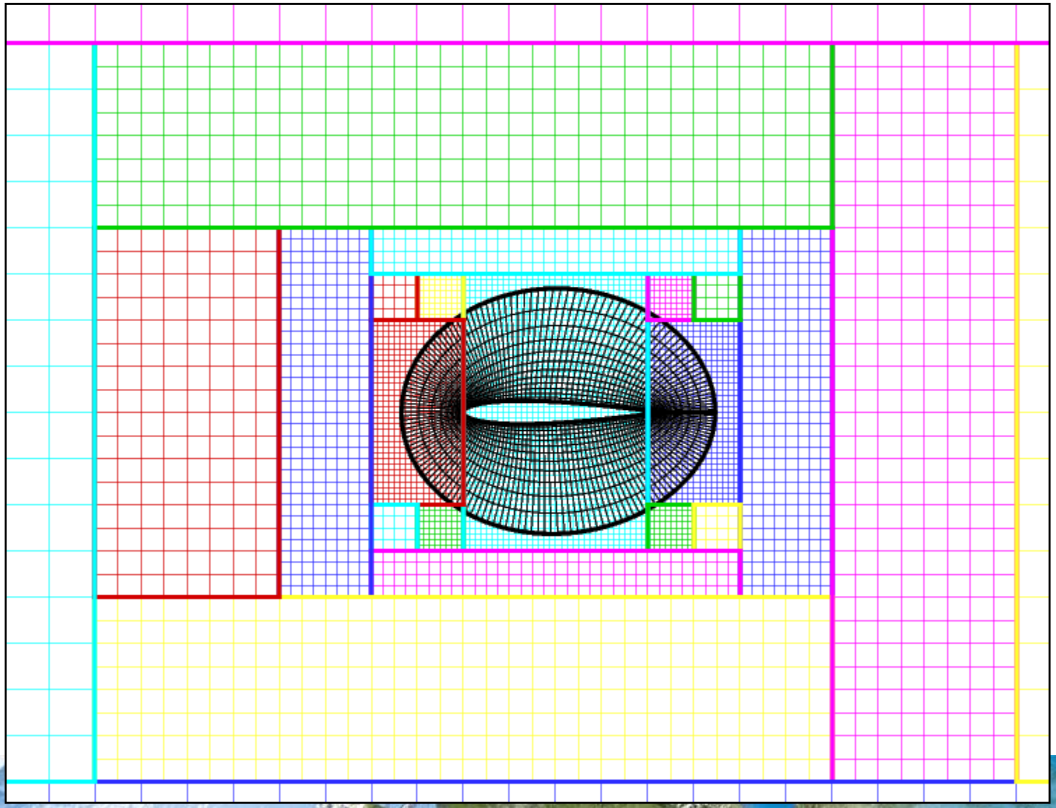
In the past: Only available as sequential postproc. tool
Now: Parallel version directly integrated into TAU

Cartesian Background Grid Generator

Problem: Manual generation of background grid with sufficient overlap & resolution cumbersome and time-consuming



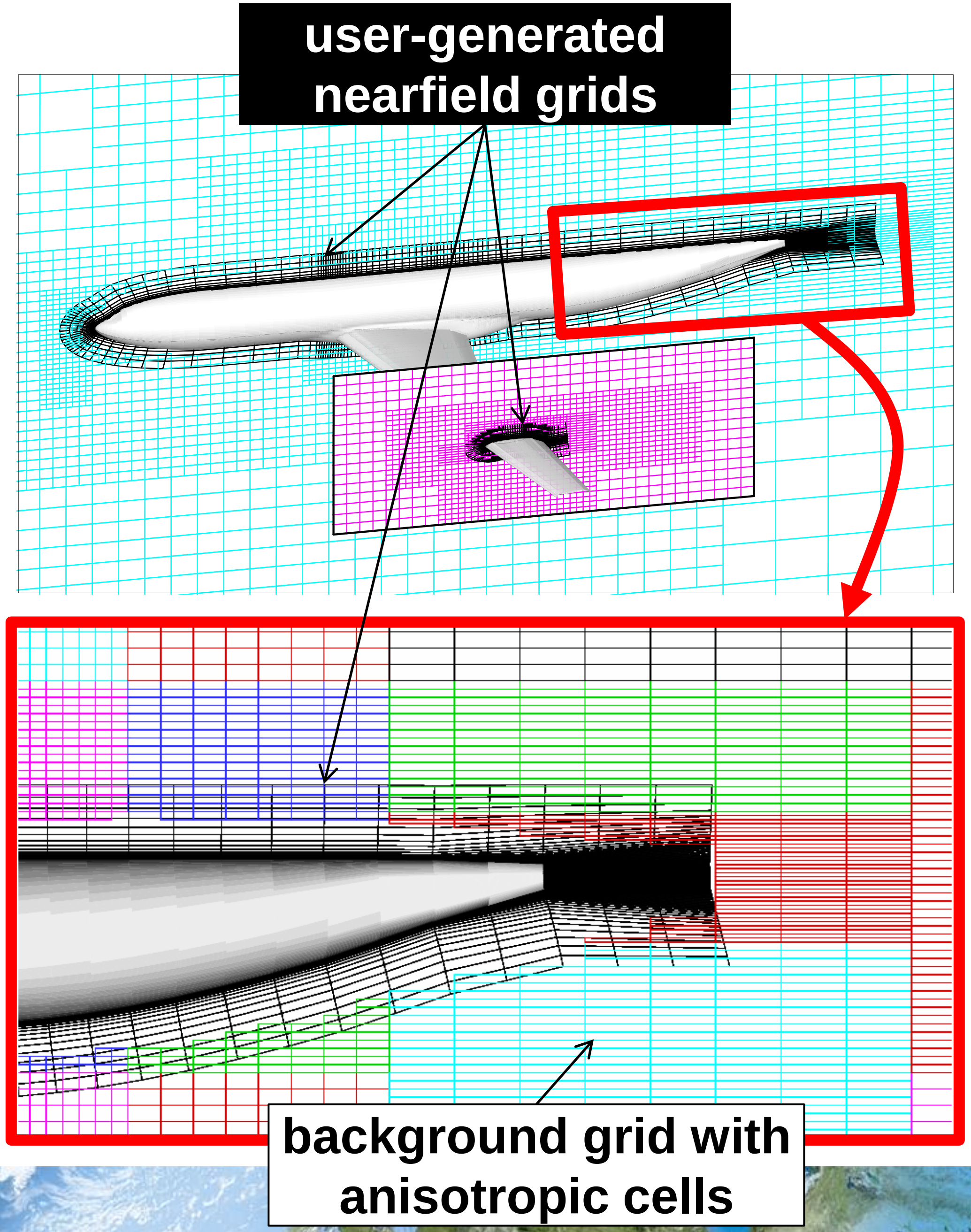
Idea: Automatic generation of Cartesian multiblock grids with hanging nodes (only FLOWer; TAU does not feature hanging nodes capability yet)



Cartesian Background Grid Generator

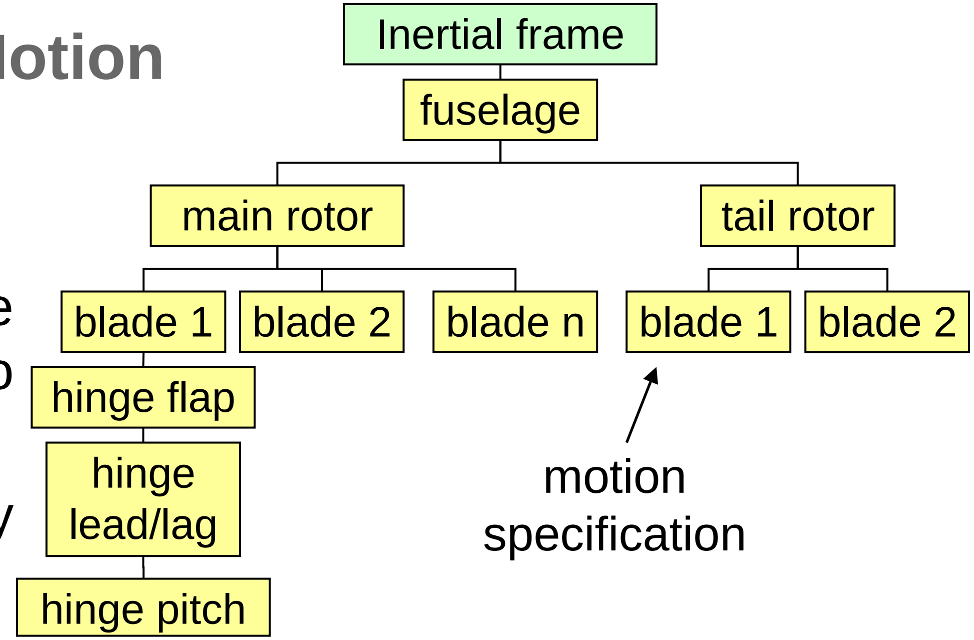
Features:

- Very coarse initial background grids (8x8x8 cells) are adapted consecutively to the nearfield grid's cell sizes
- Anisotropic refinements possible
  => Reduction of interpolation errors
  => Prevents from insufficient cell overlap
- Minimisation of the number of blocks by automatic concatenation



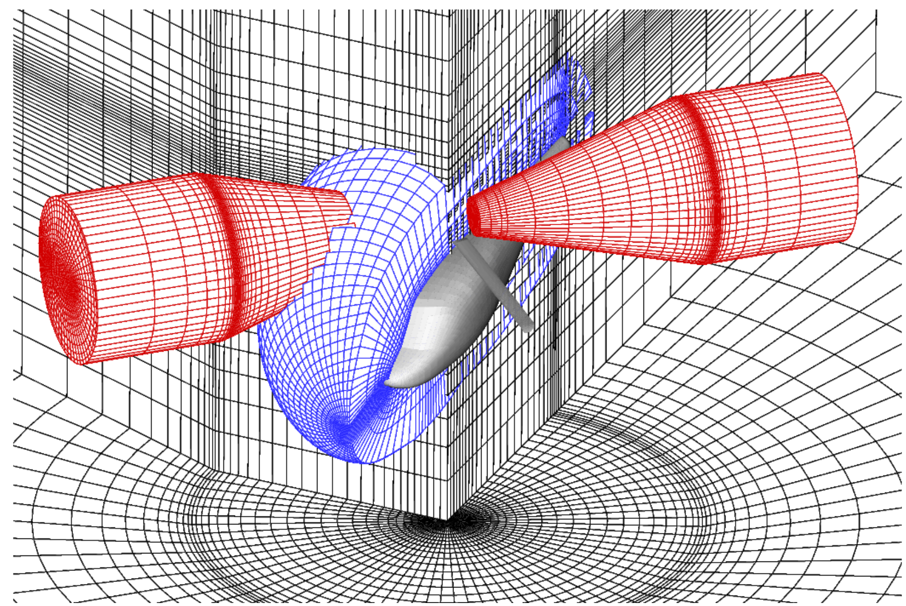
DLR

Overset Grids in Relative Motion



Specification of rigid body motions

- Tree-like data structure (=hierarchy) is used to prescribe grid motion
- Any grid can be linked to any motion specification
- TAU code: grid motion can be set conveniently (required for 6DoF app.) using TAU's Python interfaces

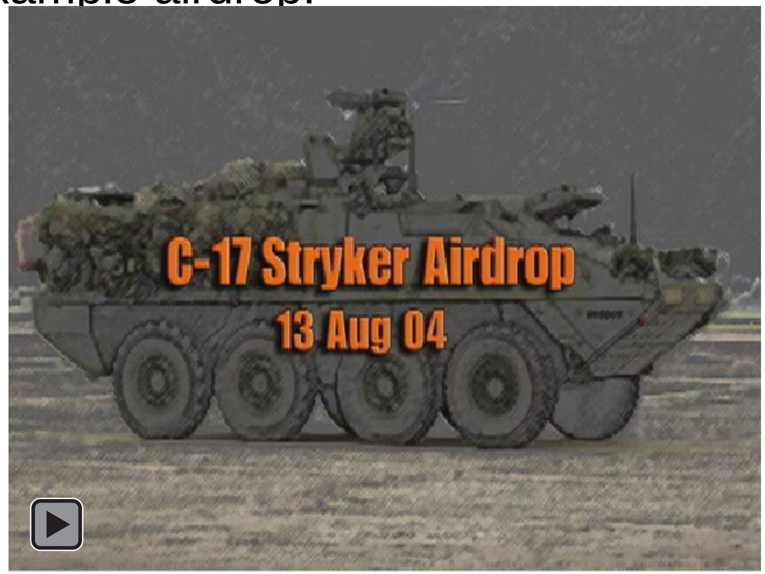


Applications

Coupled CFD-6DoF Simulation of Airdrop Scenario

MiTraPor Test Case

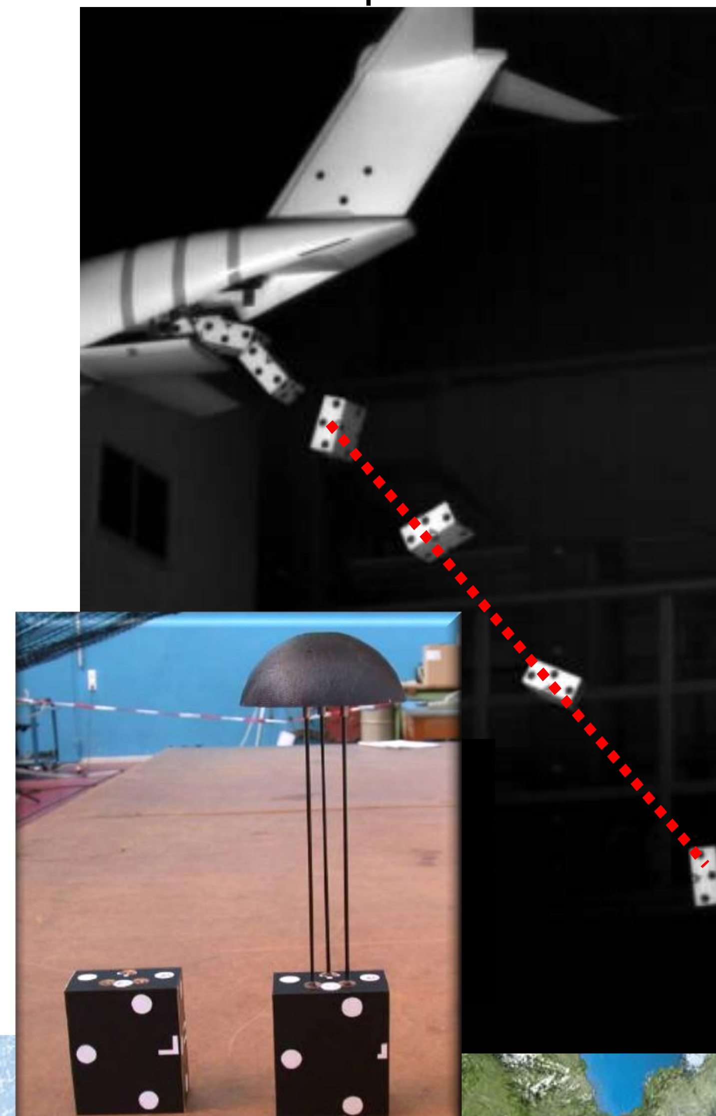
Example airdrop:



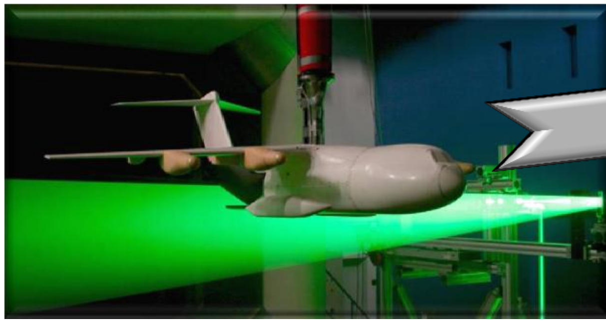
http://www.youtube.com/watch?v=eQwJnVad5L4

- Measurement of location of generic boxes w/ and w/o parachute
- Flow conditions:
  v_{inf} = 18m/s, α = 6°, Re =4x10^5

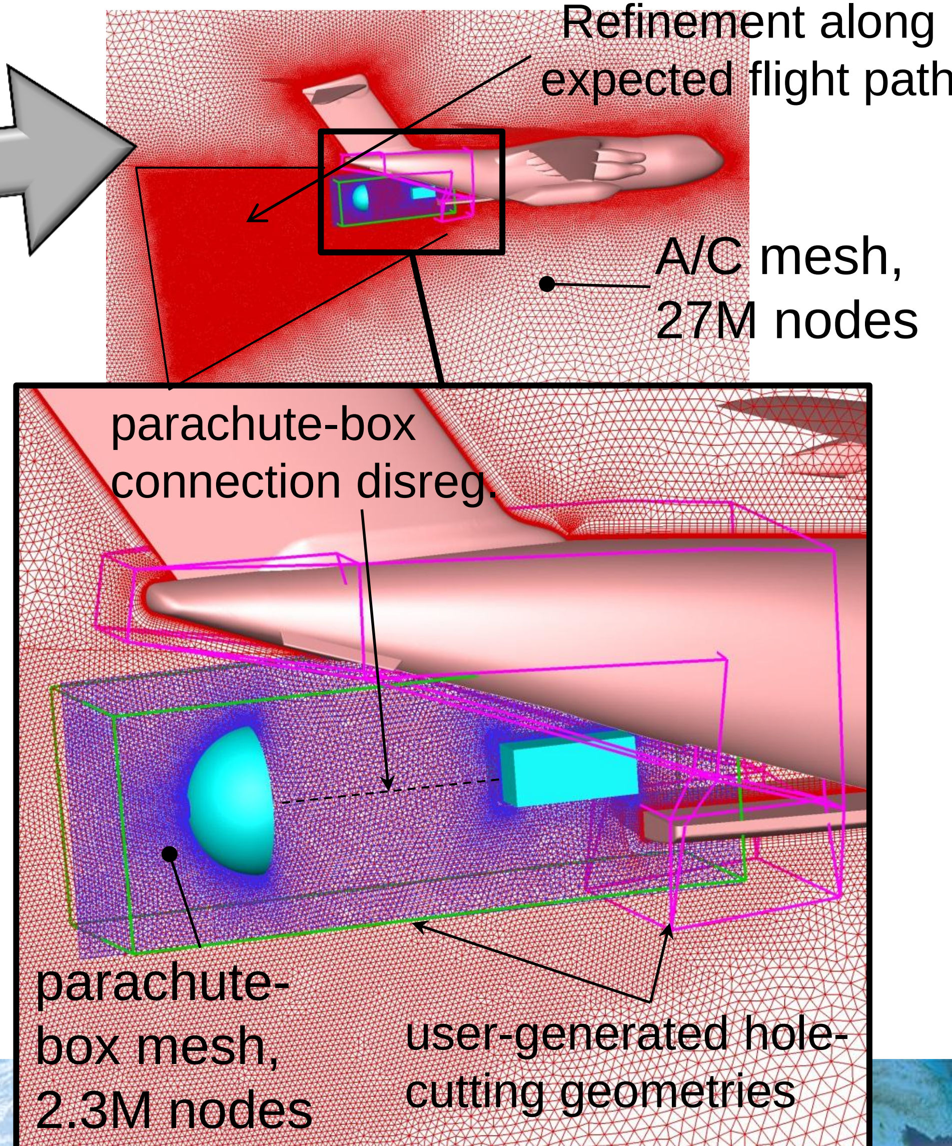
MiTraPor airdrop:



Coupled CFD-6DoF Simulation of Airdrop Scenario
MiTraPor Test Case



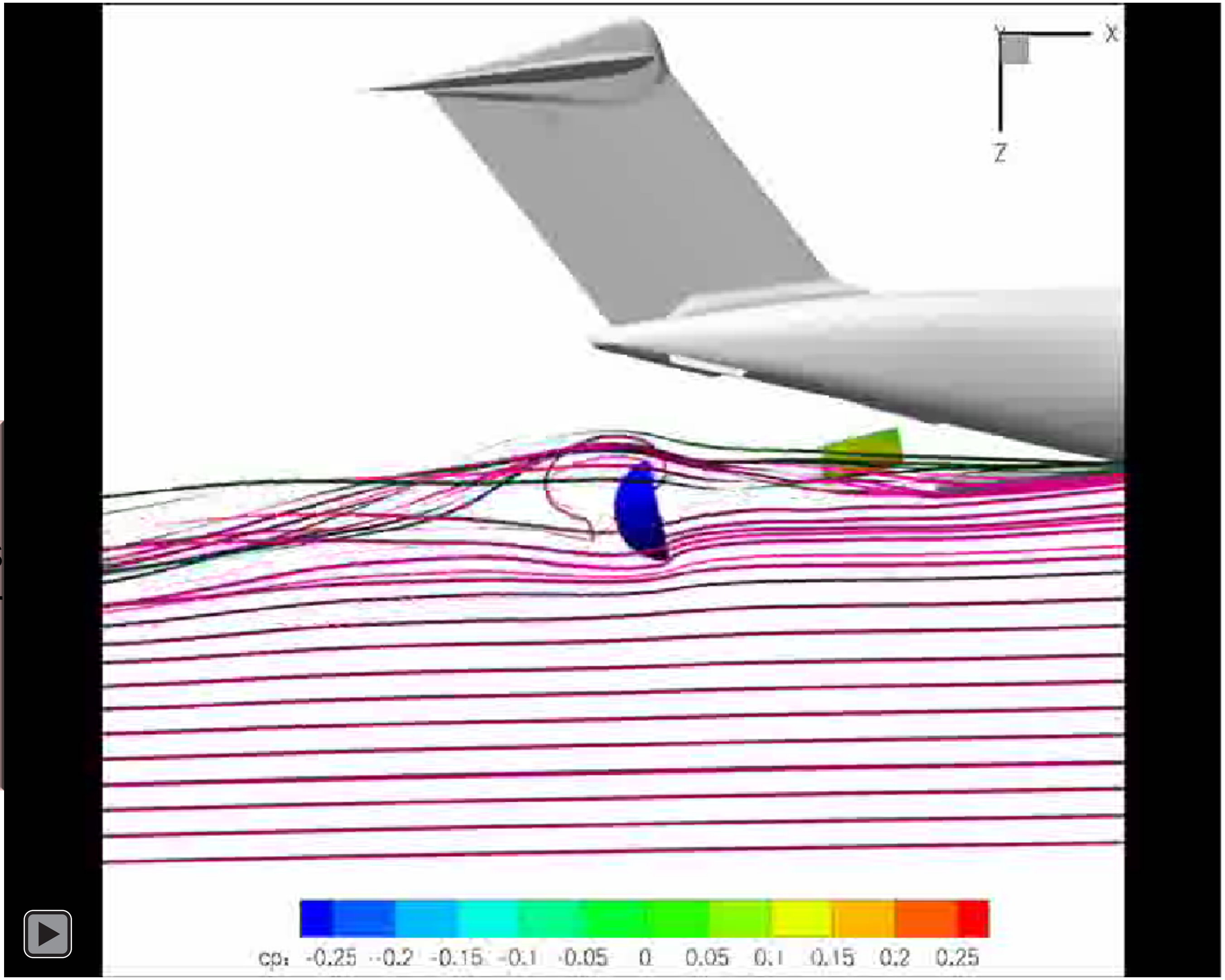
Computational setup:



- Making use of overset grid technique with semi-automatic hole cutting
  - Unstruct. background A/C mesh
  - Unstruct. mesh around parachute-box config.
- Tight coupling of TAU to 6DoF code

Coupled CFD-6DoF Sim. of Airdrop Scenario

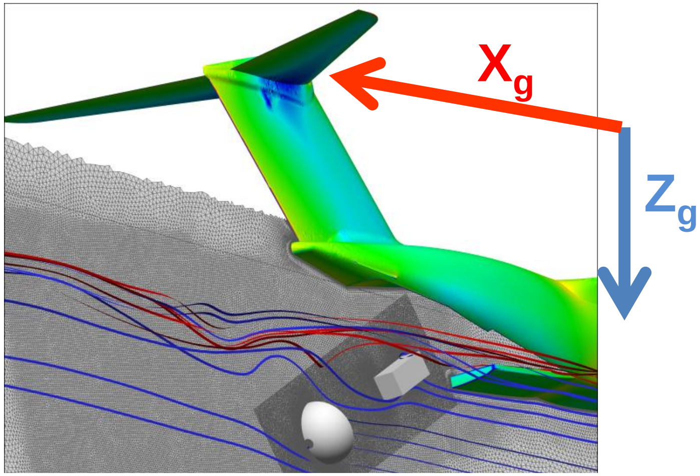
Computing time:
42.6M pts., 144 procs: 160h (~7d) for 0.33s real time, 53min per phys. time step @ 600Hz resol.

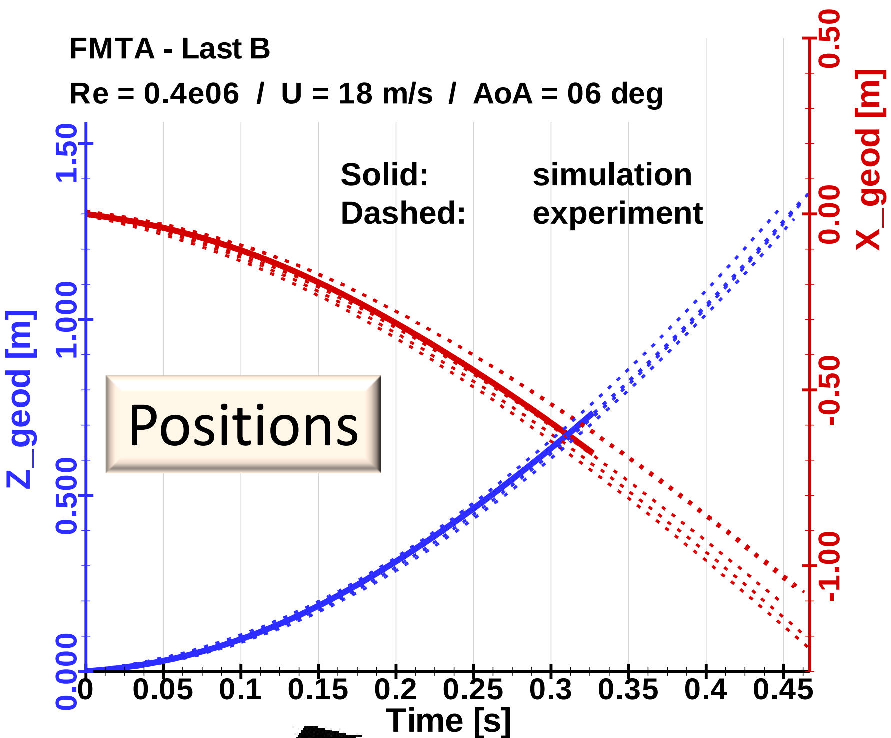


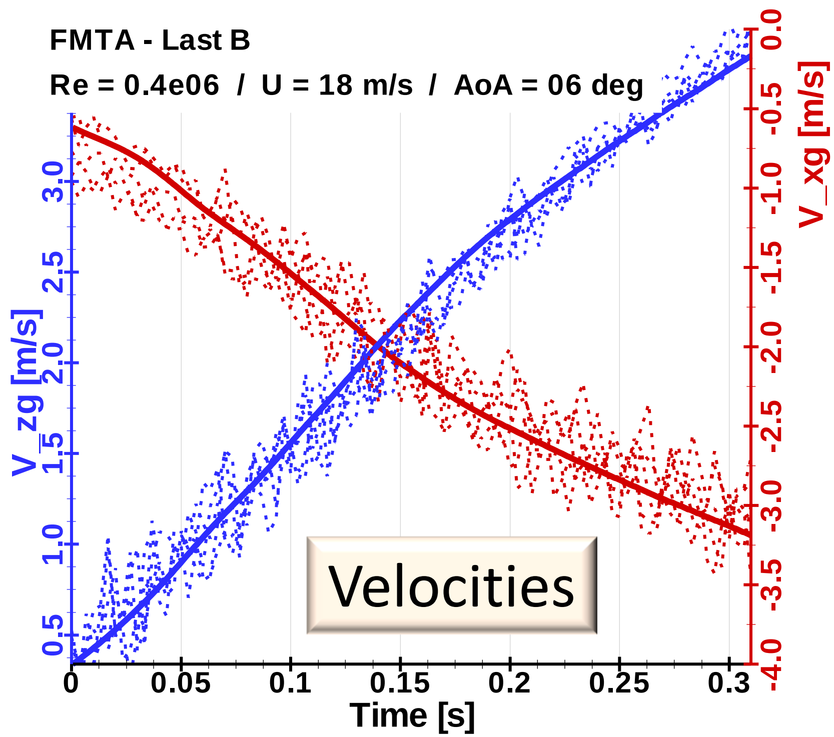
DLR

Coupled CFD-6DoF Simulation of Airdrop Scenario:

MiTraPor Test Case – Comparison of Computed & Measured Trajectories

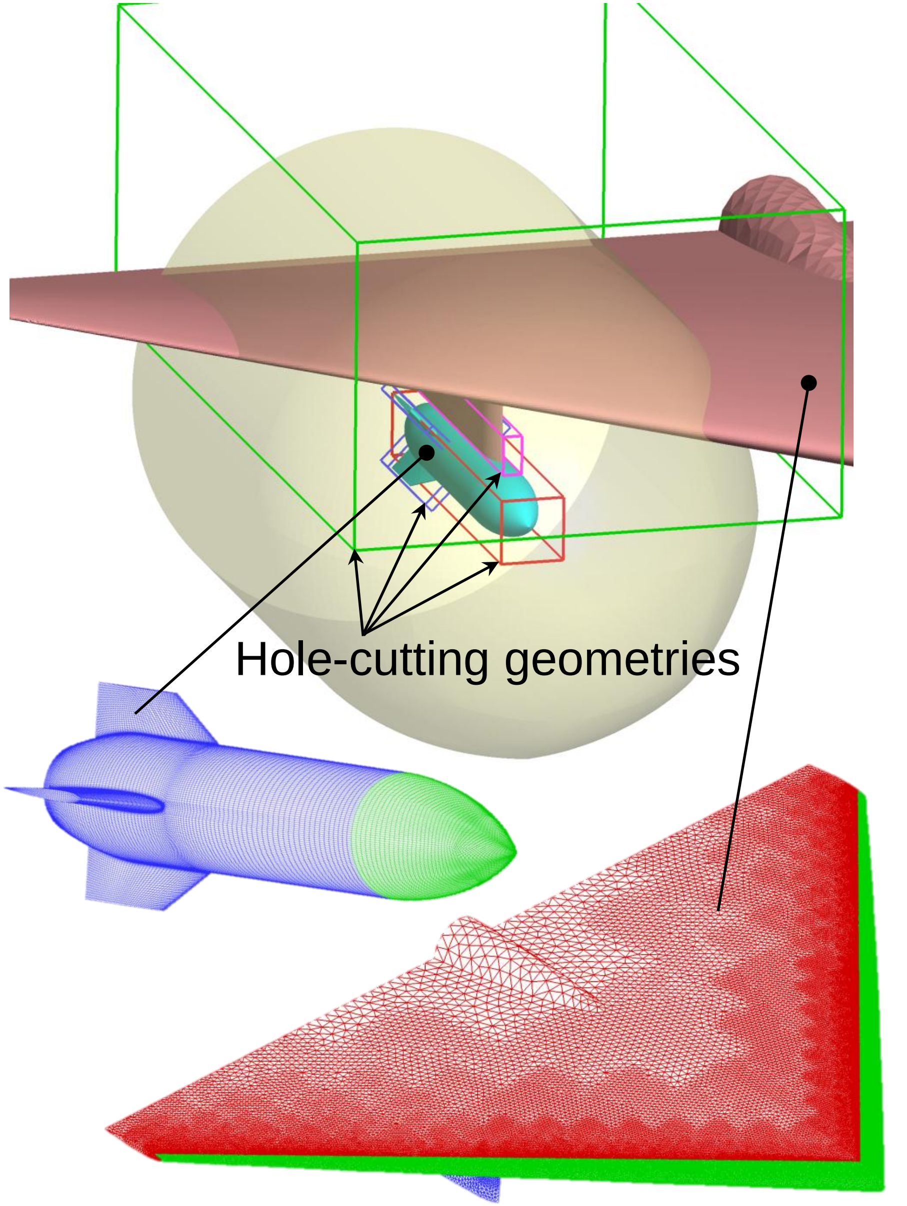






Coupled CFD-6DoF Sim. of Store Release
AFRL* Test Case

- Activity within GARTEUR SIG 47
- Flow conditions: Ma = 0.95, α = 0.0°, Re = 4.1m
- Experiment conducted by AFRL, see RTO-TR-26, ch. 23
- Meshes:
  - **Store**: Structured Ansys ICEM-CFD HEXA Navier-Stokes mesh converted to TAU format, 3.1M nodes
  - **Delta wing**: Unstructured CentaurSoft Centaur Euler mesh, 600k nodes



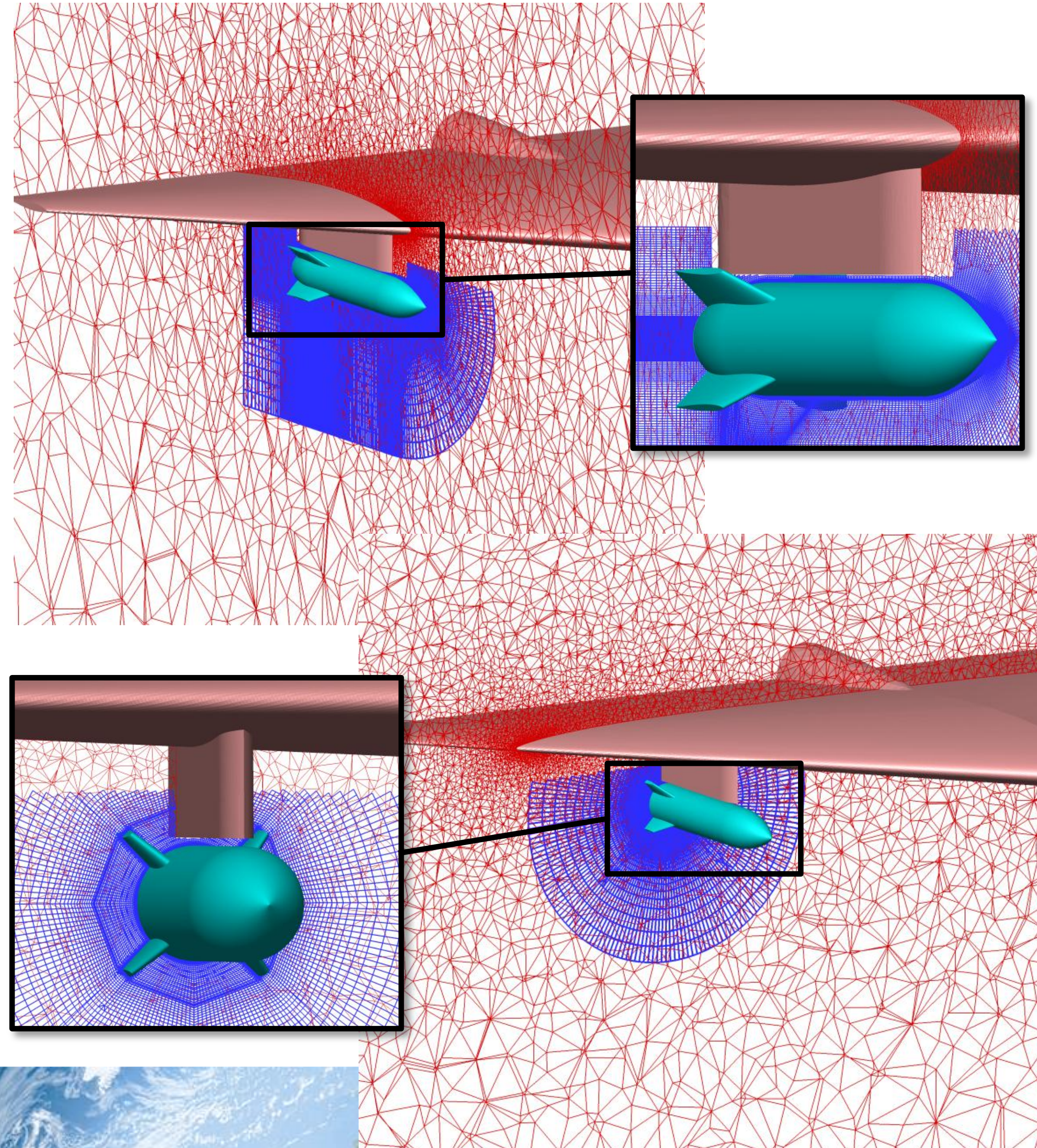
* Air Force Research Laboratory, Wright-Patterson Air Force Base

Coupled CFD-6DoF Sim. of Store Release

AFRL Test Case

Difficulty:

At t=0 store & pylon are very close



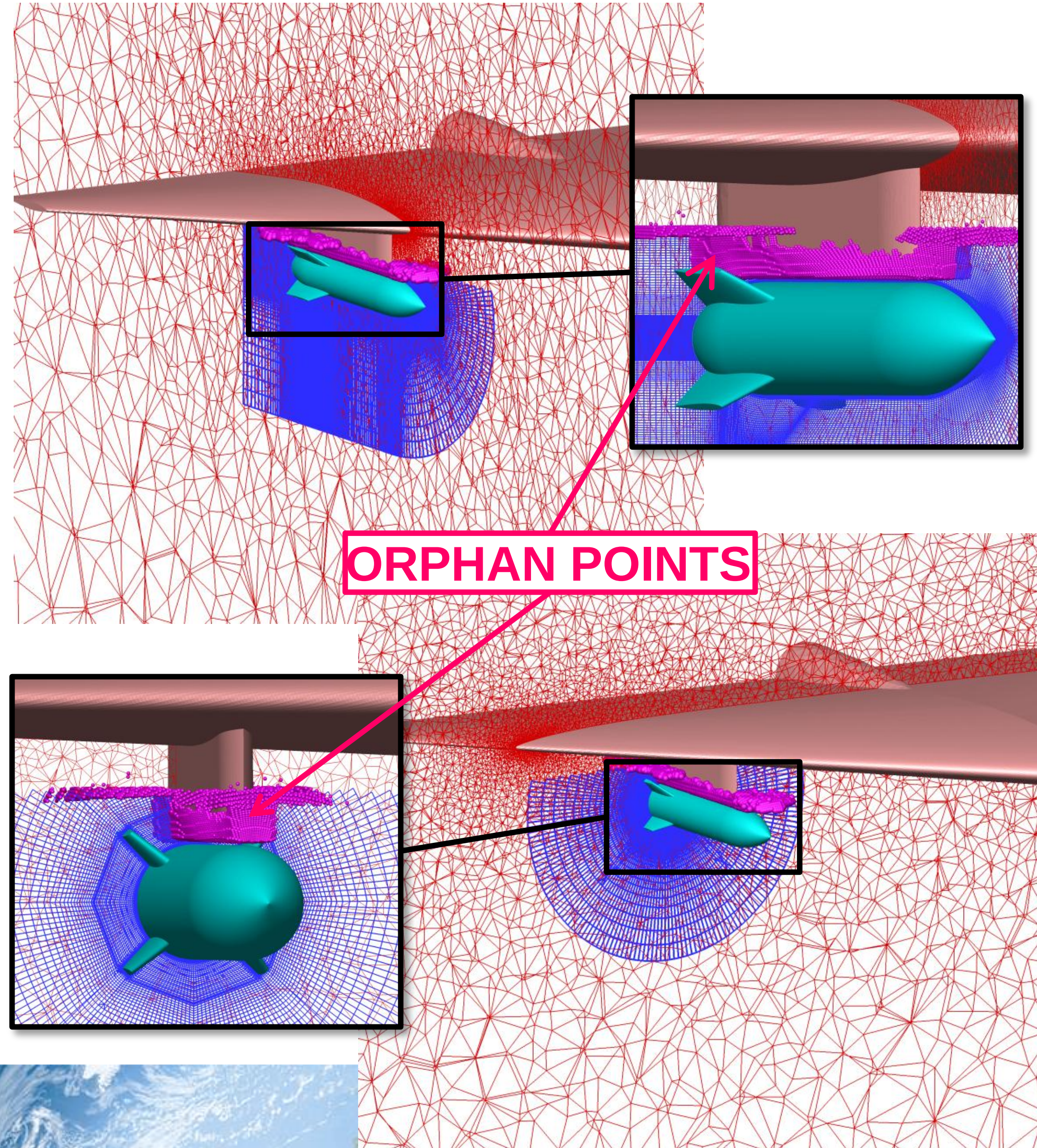
DLR

Coupled CFD-6DoF Sim. of Store Release

AFRL Test Case

Difficulty:

At t=0 store & pylon are very close => With the original mesh, not all donor cells could be found



Coupled CFD-6DoF Sim. of Store Release

AFRL Test Case

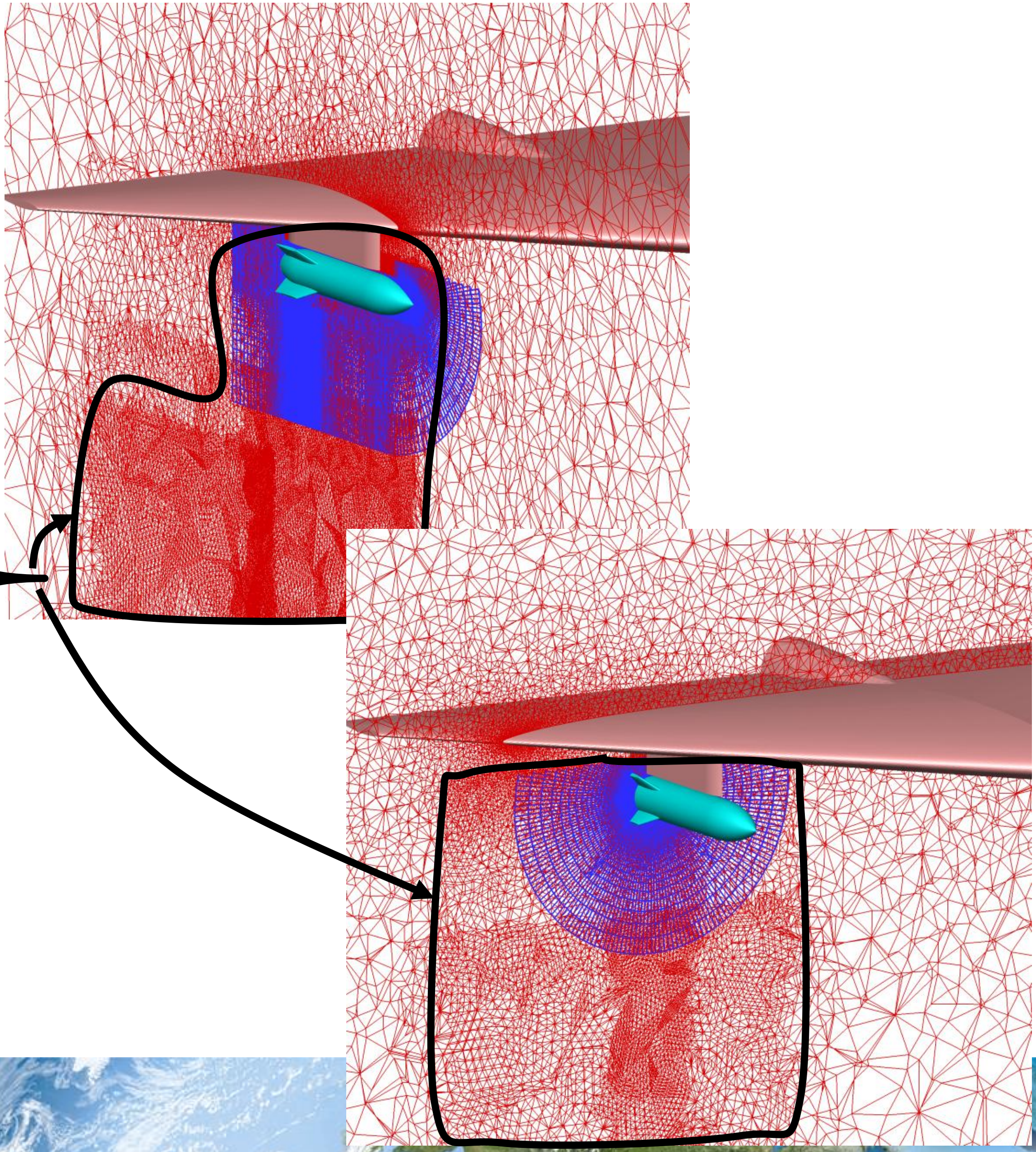
Difficulty:

At t=0 store & pylon are very close => With the original mesh, not all donor cells could be found

Approach for solving the problem:

Uniform adaptation of the delta wing mesh

- … close to the pylon
- … in expected flight path area



Coupled CFD-6DoF Sim. of Store Release

AFRL Test Case

Difficulty:
At t=0 store & pylon are very close => With the original mesh, not all donor cells could be found

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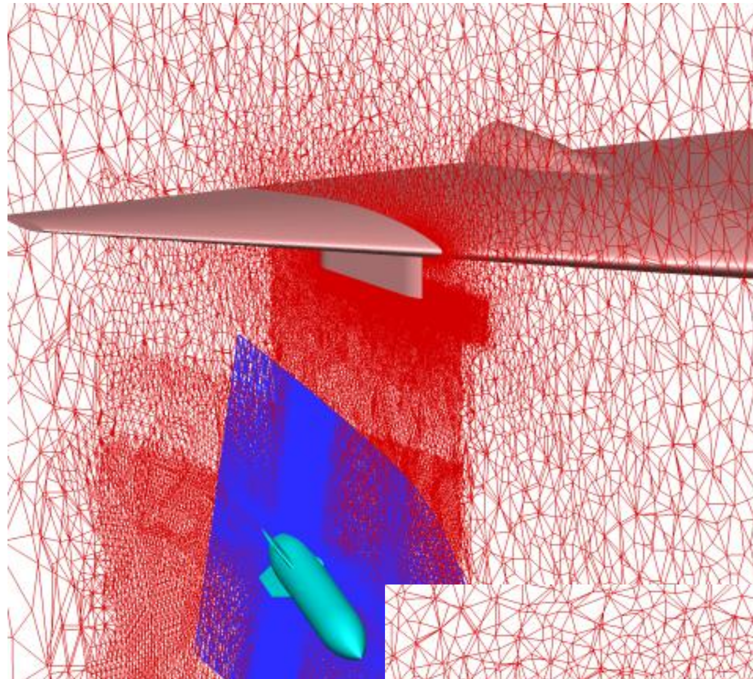
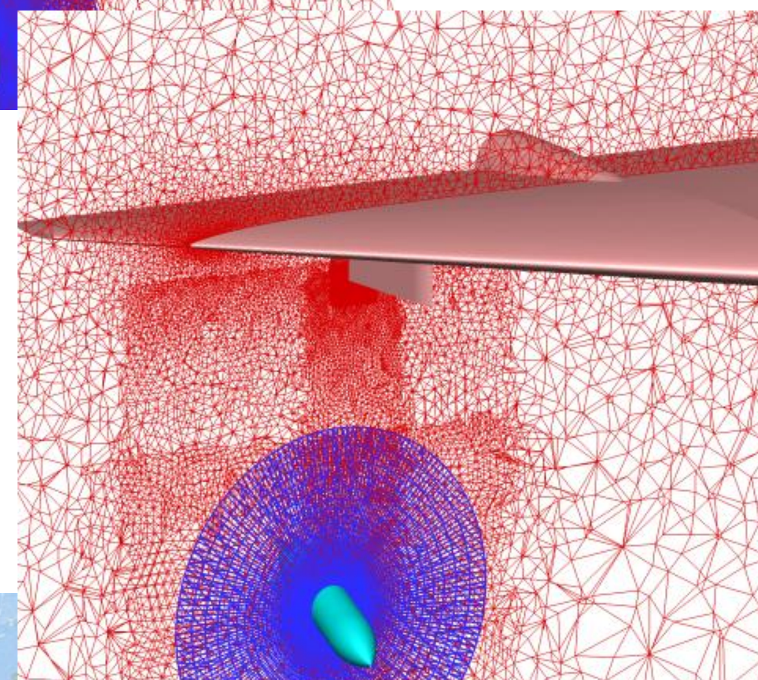
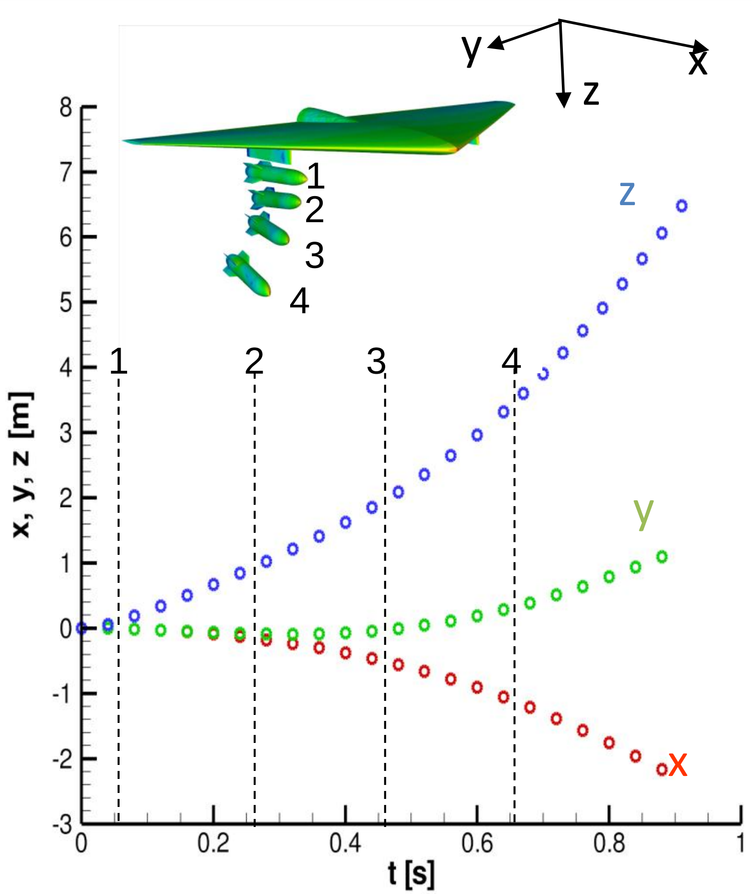


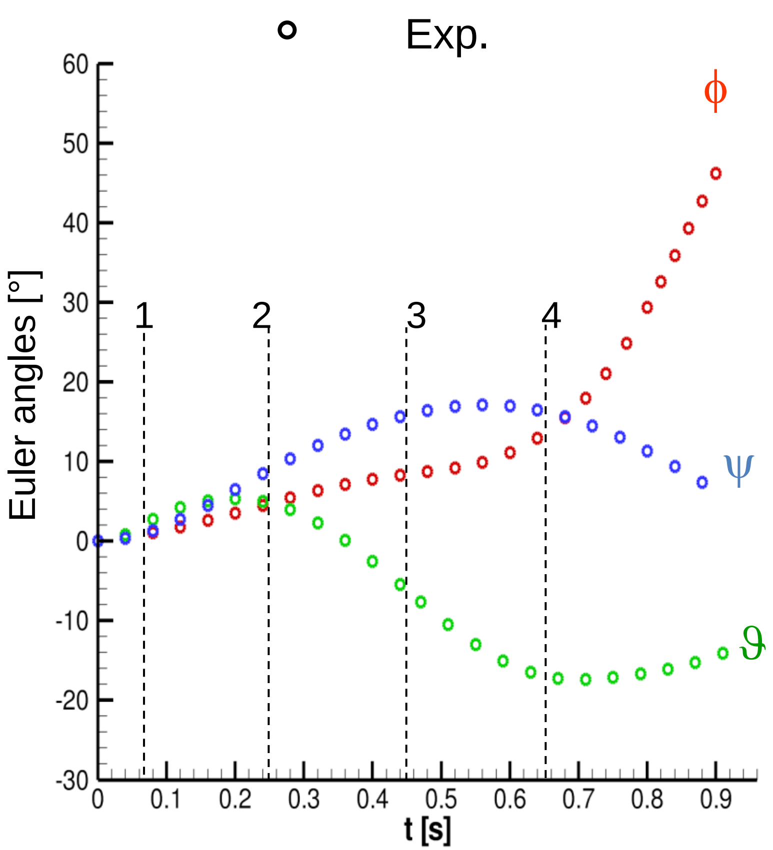
⇒With adaptation approach the simulation worked



Coupled CFD-6DoF Simulation of Store Release
AFRL Test Case



Locations



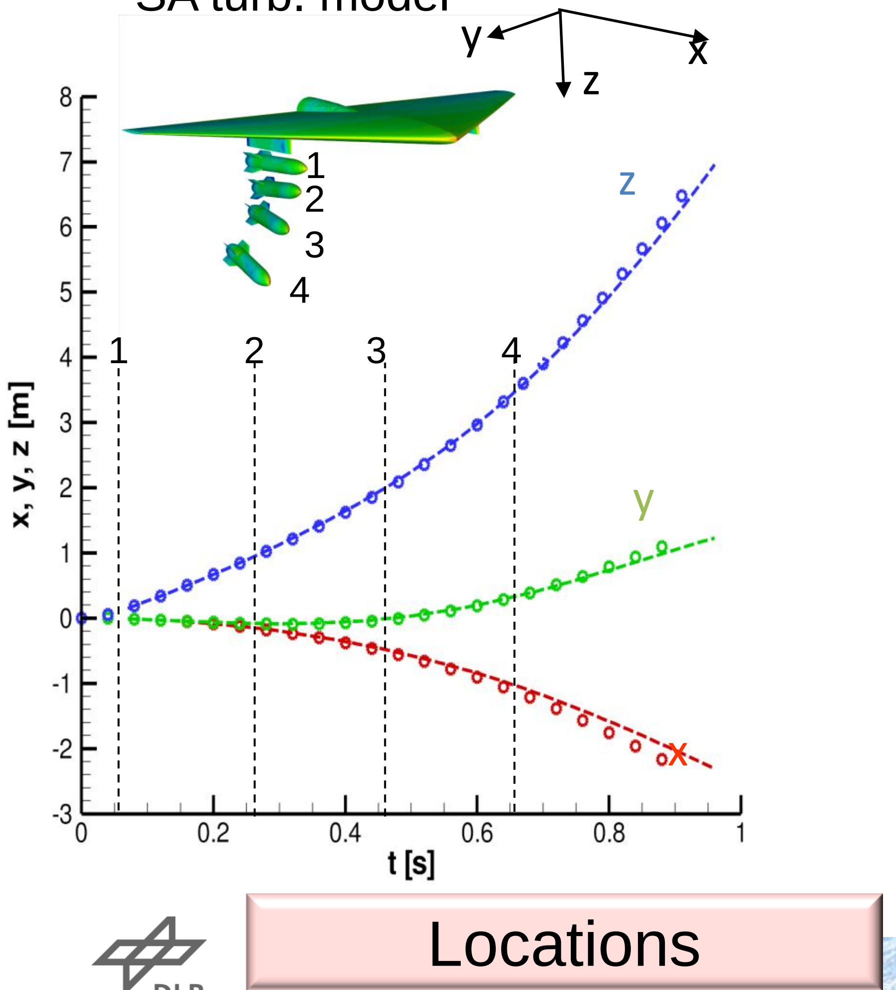
Rotations

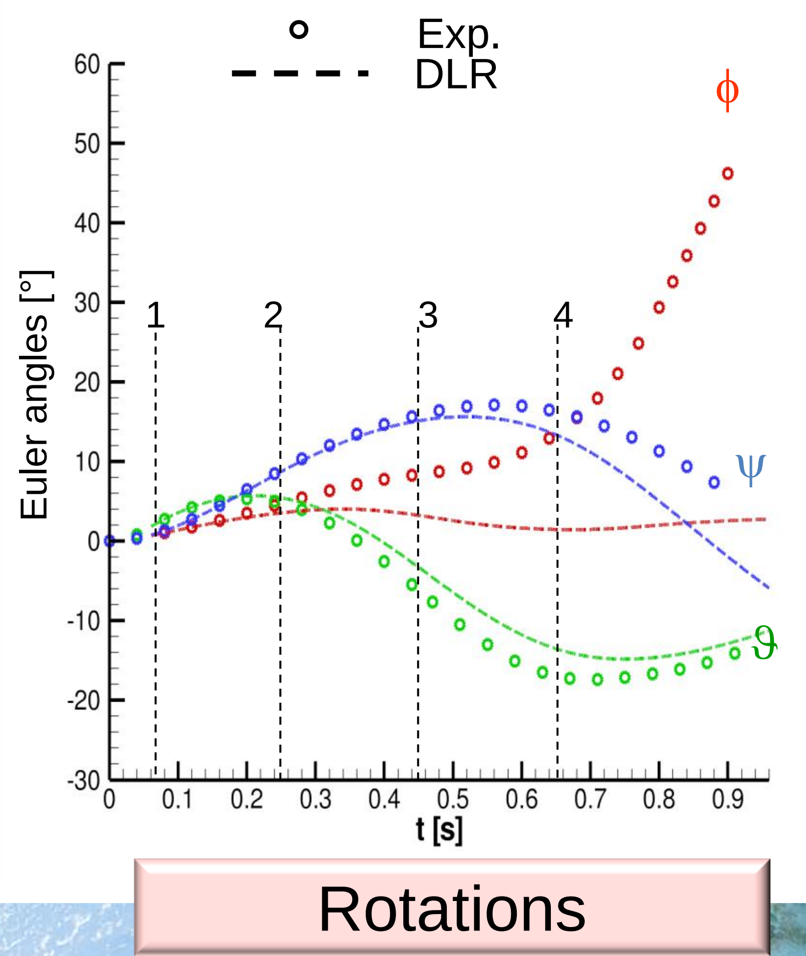
Coupled CFD-6DoF Simulation of Store Release

AFRL Test Case

DLR's simulation:

- Strong coupling of CFD-6DoF (unsteady)
- SA turb. model





Coupled CFD-6DoF Simulation of Store Release

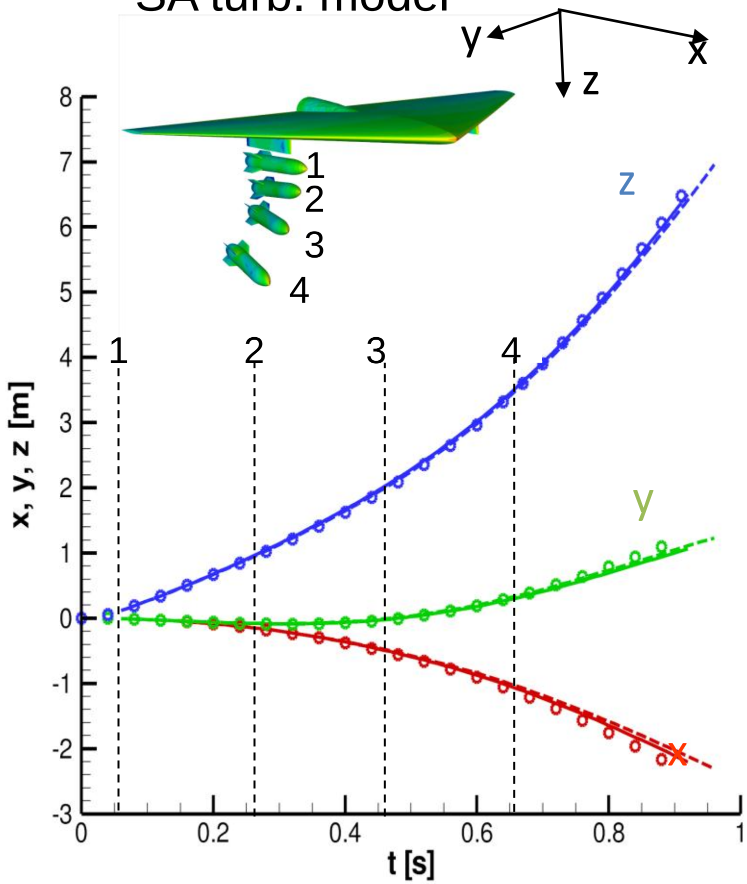
AFRL Test Case

DLR's simulation:

- Strong CFD-6DoF coupling (unsteady)
- SA turb. model

ONERA's simulation:

- Quasi-steady coupling CFD-6DoF
- SA turb. model



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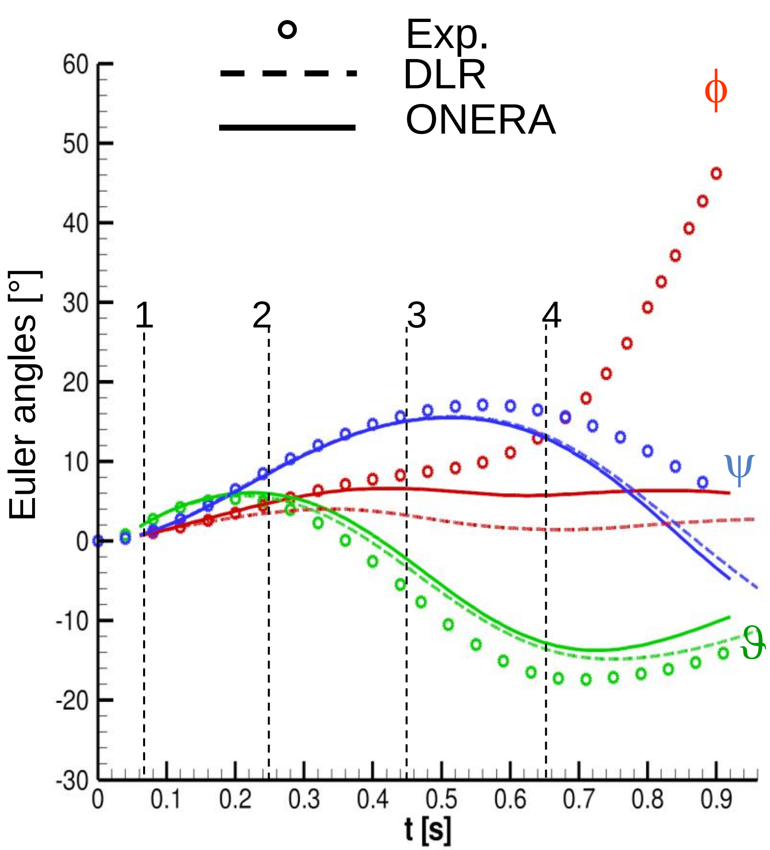


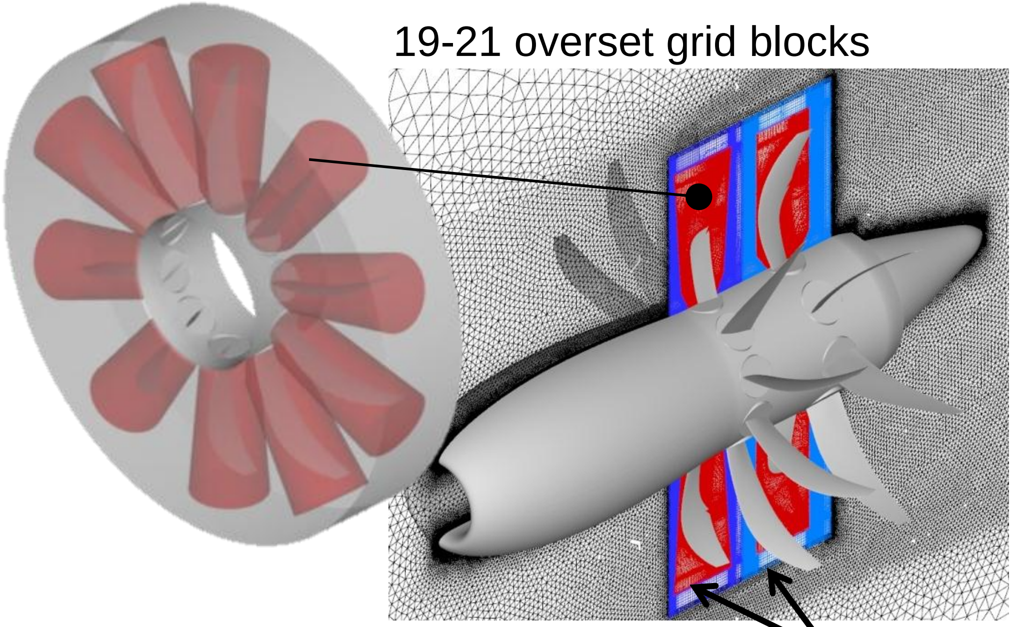
Rotations

Open Rotor Applications:
CROR Flow Analysis

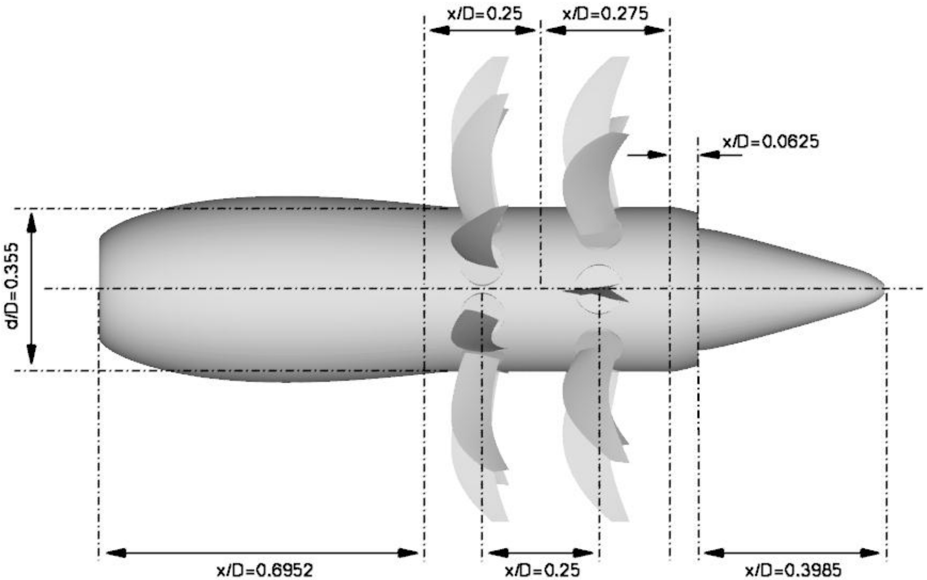
Here: Isolated rotor case

- Unstruct. background grid, struct. spinner & blade grids, „pre-generated“ holes used

19-21 overset grid blocks



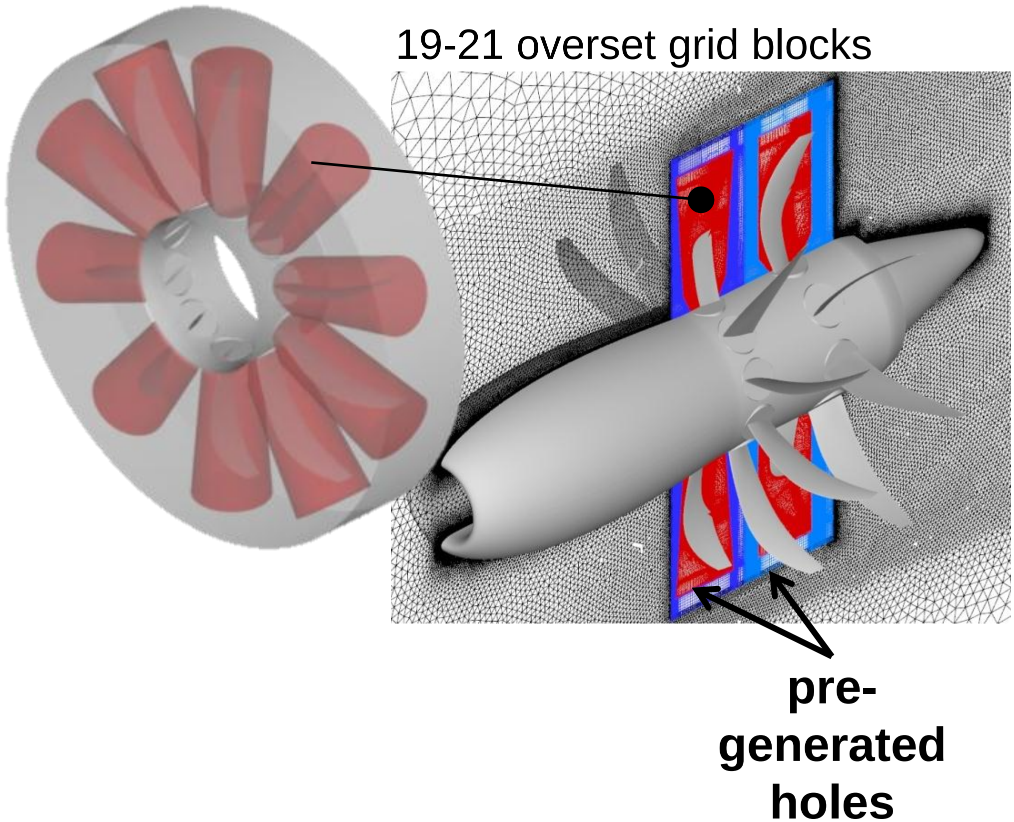
pre-generated holes

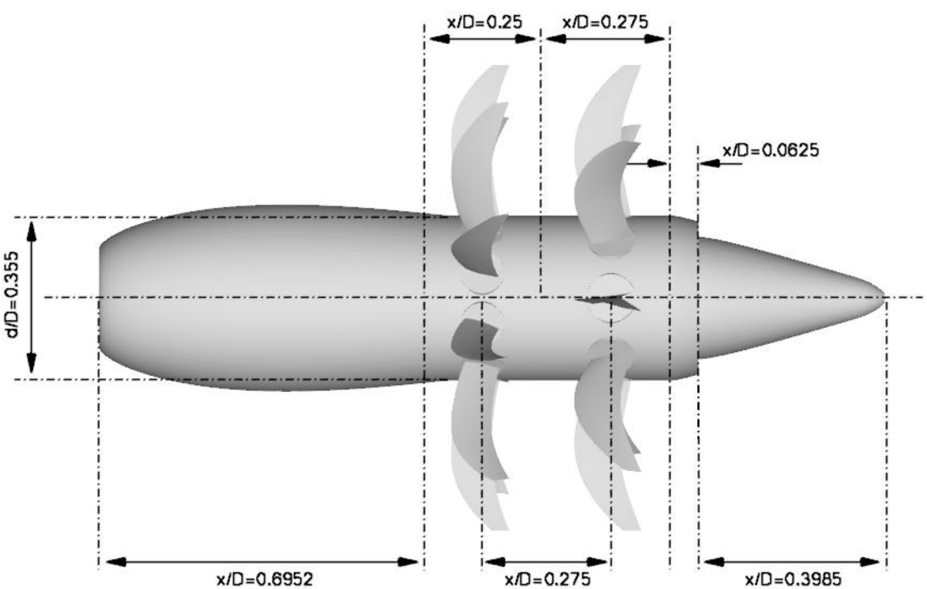


Open Rotor Applications:
CROR Flow Analysis

Here: Isolated rotor case

- Unstruct. background grid, struct. spinner & blade grids, „pre-generated“ holes used
- Perform. & noise analysis of many config. variations

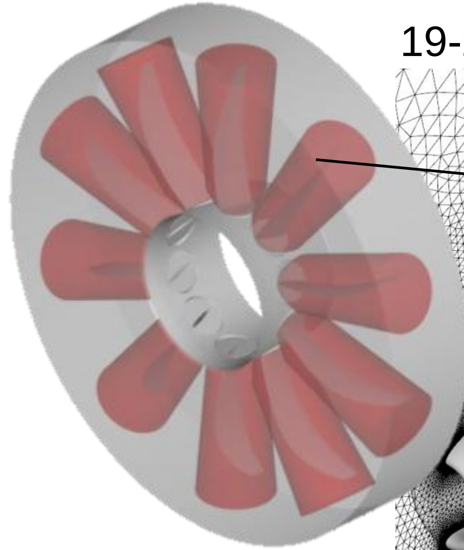




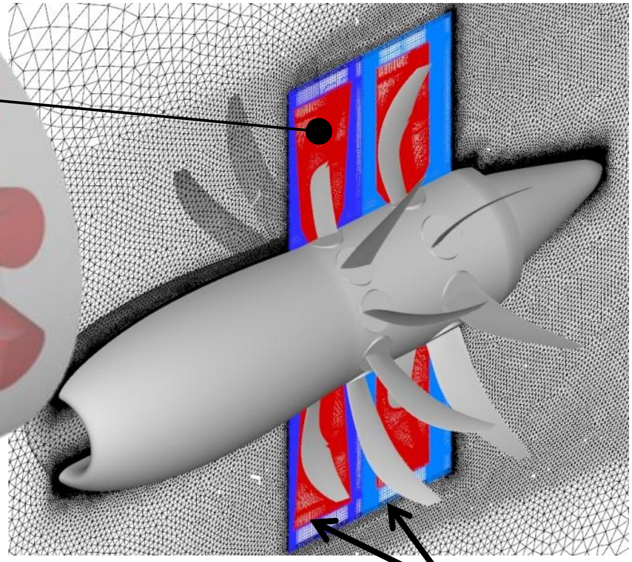
Open Rotor Applications:
CROR Flow Analysis

Here: Isolated rotor case

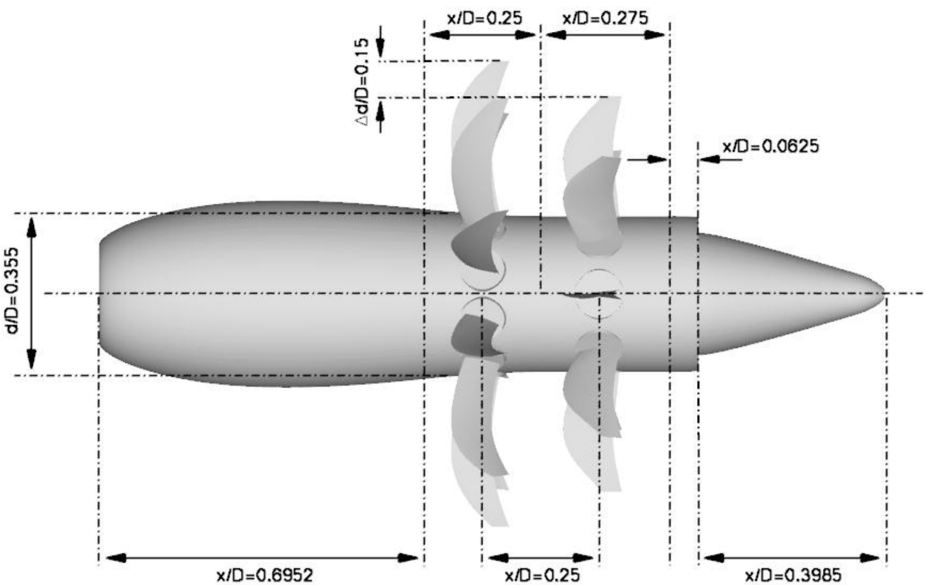
- Unstruct. background grid, struct. spinner & blade grids, „pre-generated“ holes used
- Perform. & noise analysis of many config. variations



19-21 overset grid blocks



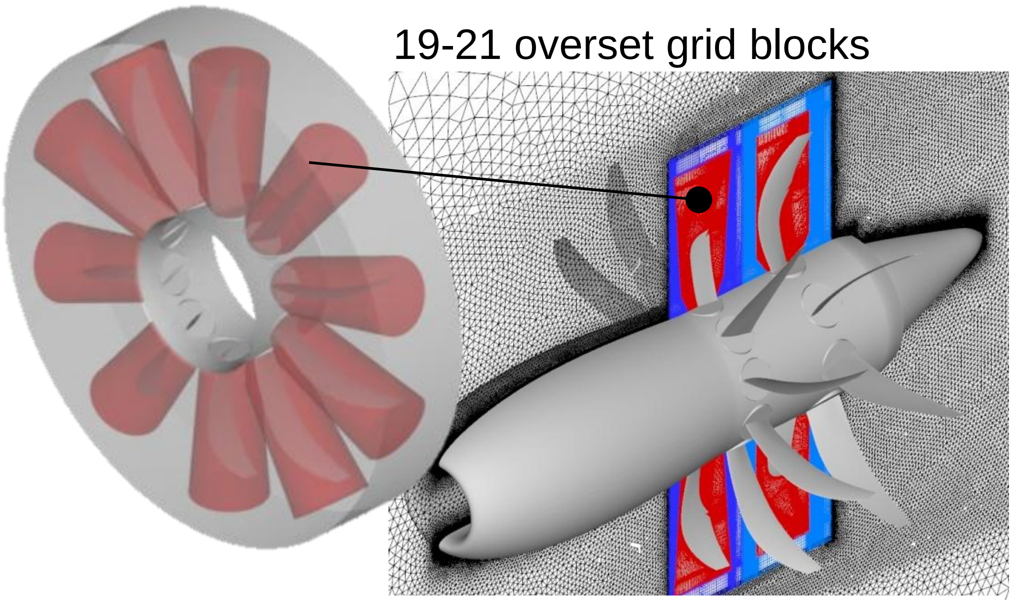
pre-generated holes

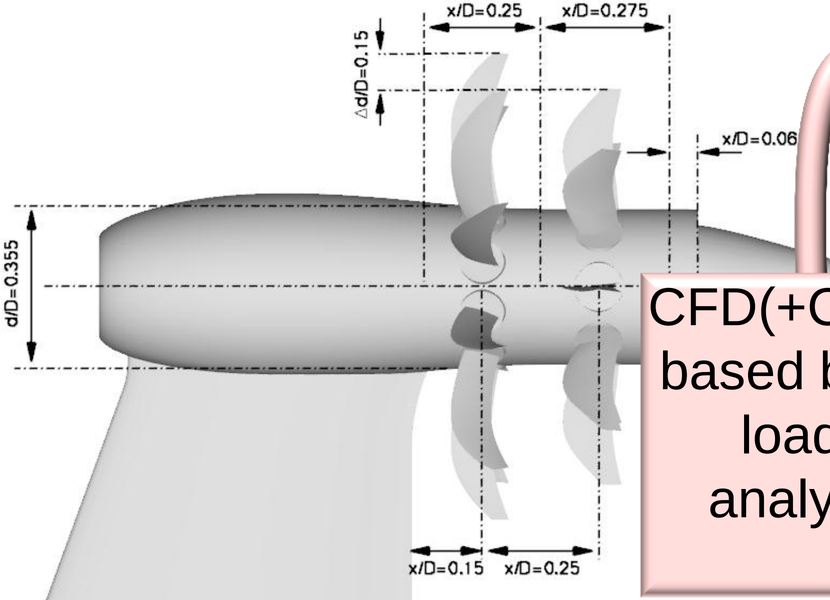


Open Rotor Applications:
CROR Flow Analysis

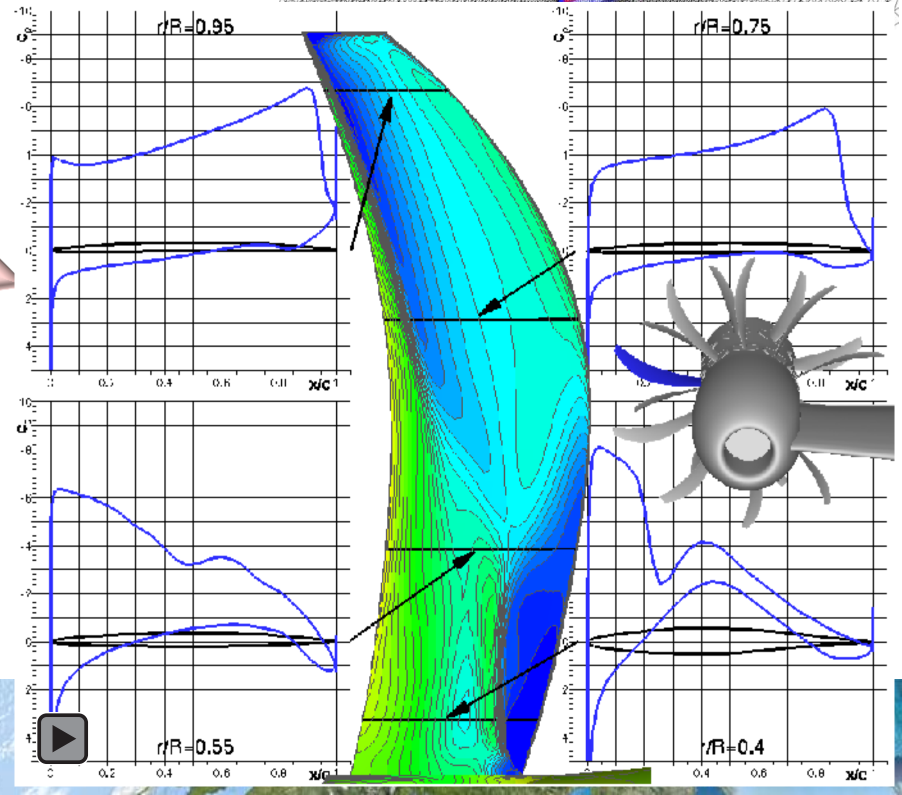
Here: Isolated rotor case

- Unstruct. background grid, struct. spinner & blade grids, „pre-generated“ holes used
- Perform. & noise analysis of many config. variations
- Comp. time: 65M nodes case, 360 procs..: 720 timesteps per revolution necessary => ~4d per rev; 6-12 revs necessary => ~1.5-3 weeks





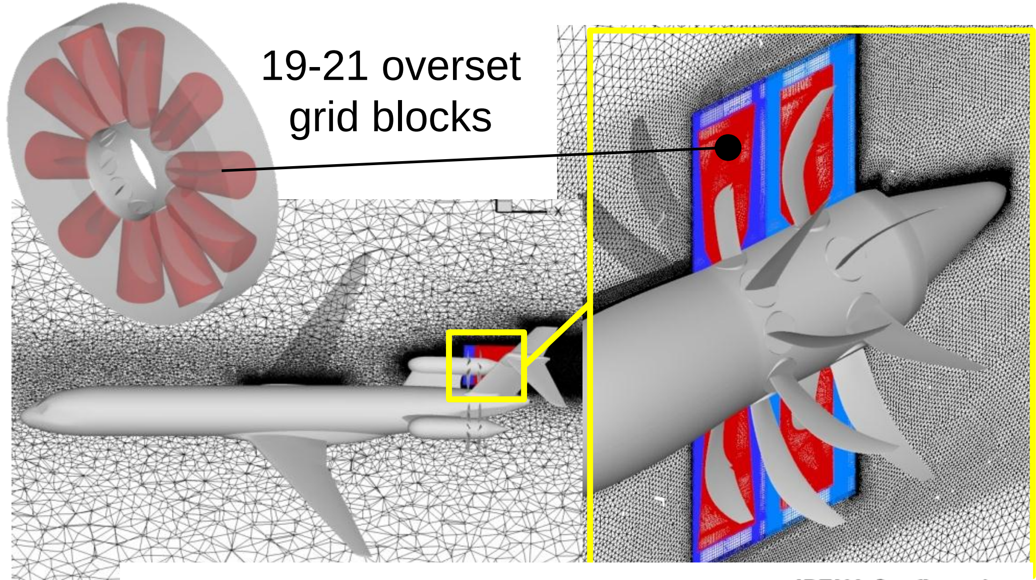
CFD(+CSM)-based blade loads analysis



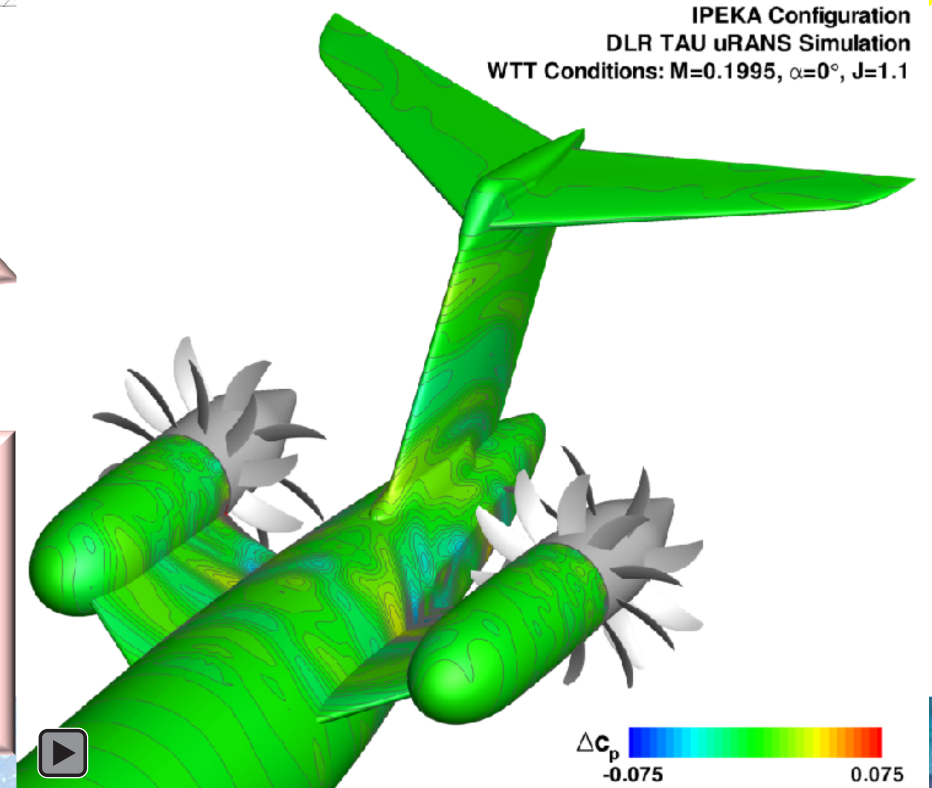
Open Rotor Applications:
CROR Flow Analysis

Here: Integrated rotor case

- Unstruct. background grid, struct. spinner & blade grids, „pre-generated“ holes used

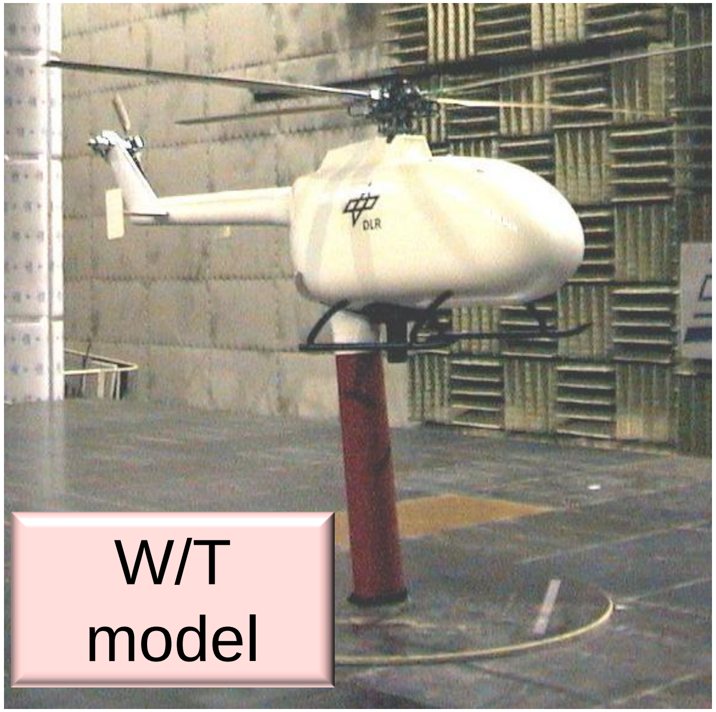


CFD-based airframe loads analysis



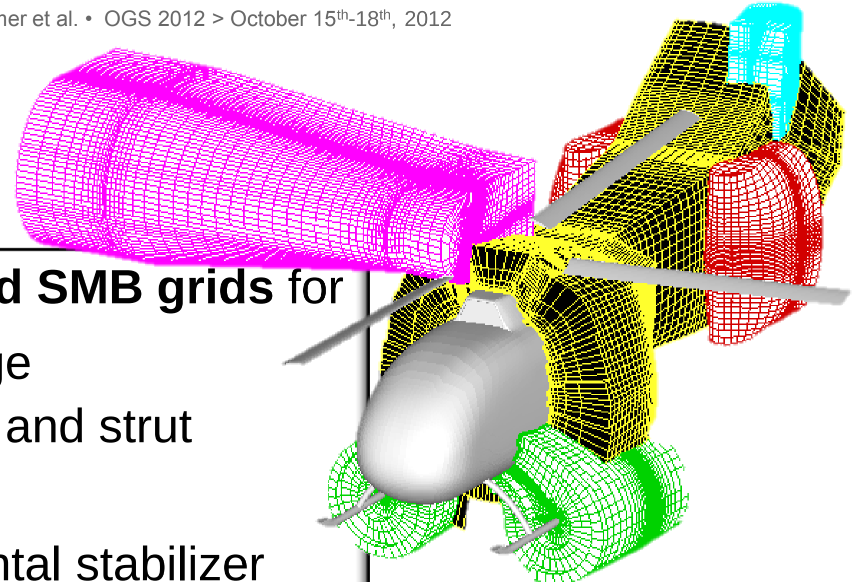
DLR

Helicopter Applications:
BO105 Case

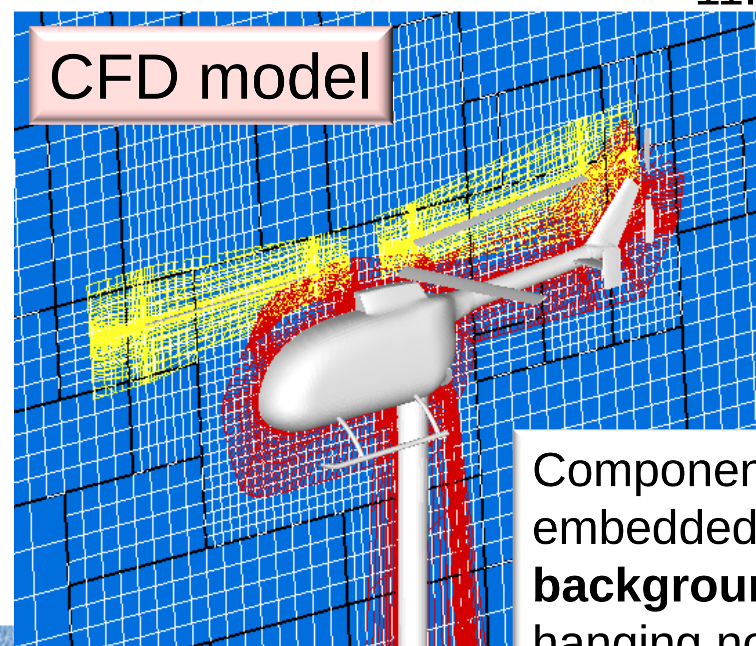


$a_{fuselage} = -5.2$
$M_{\infty} = 0.1766$
$M_{MR} = 0.652$
$M_{TR} = 0.63$
$Q_{MR} = 10.5° - 6.3° \sin(Y)$
$+ 1.9° \cos(Y)$
$Q_{TR} = 8.0°$

Nearfield SMB grids for
- fuselage
- spoiler and strut
- skids
- horizontal stabilizer
- main rotor and tail rotor



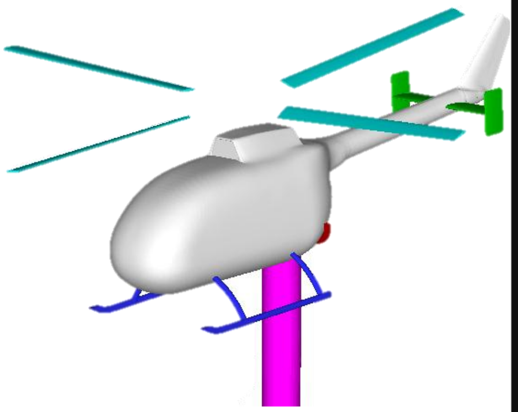
Total: 480 blocks, 11.8m nodes

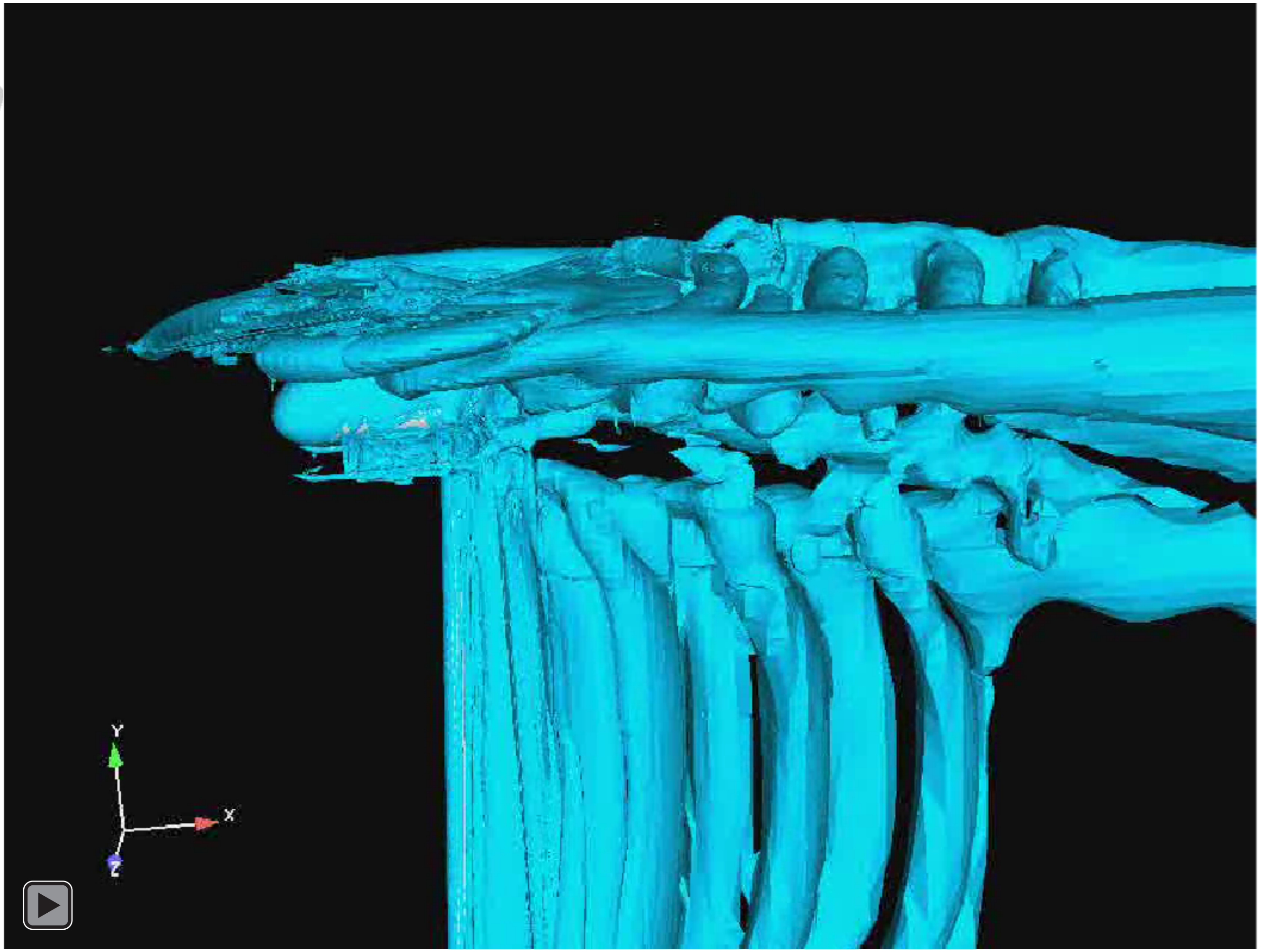


Component grids are embedded in **Cartesian background grid** with hanging nodes

Helicopter Applications:
BO105 Case

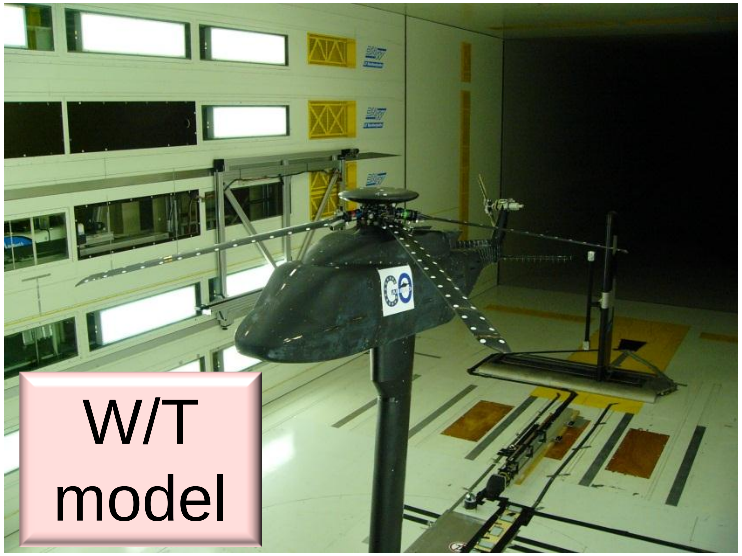
λ_2 iso-surfaces

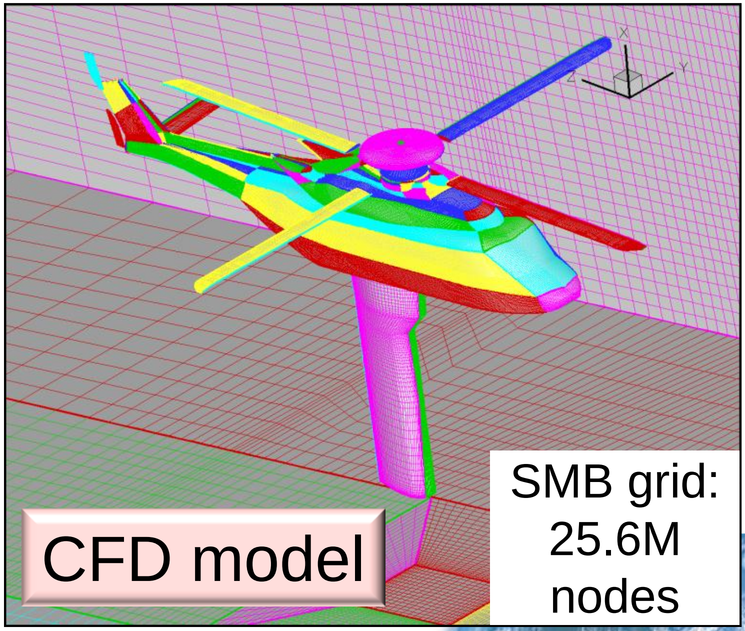


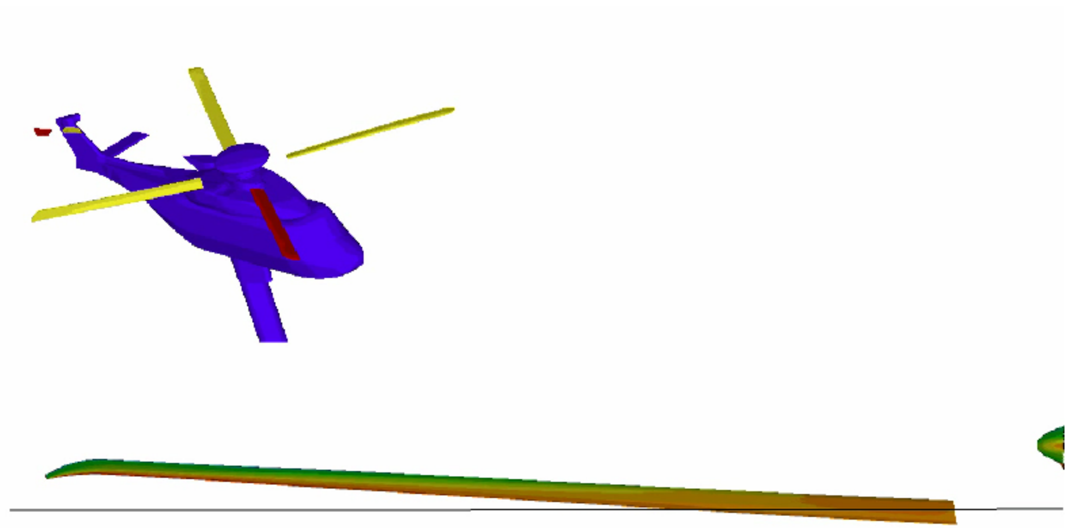


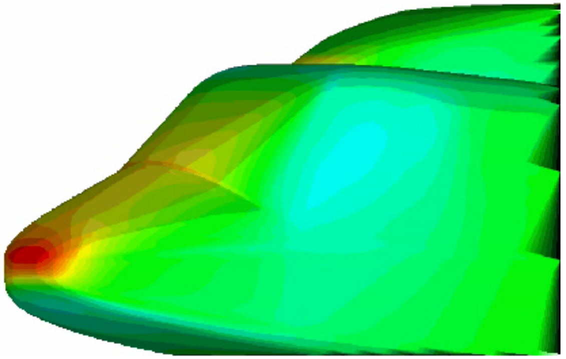
Helicopter Applications: **GOAHEAD Case**

FLOWer-HOST* loose coupling
=> trim + elastic blade defo. considered





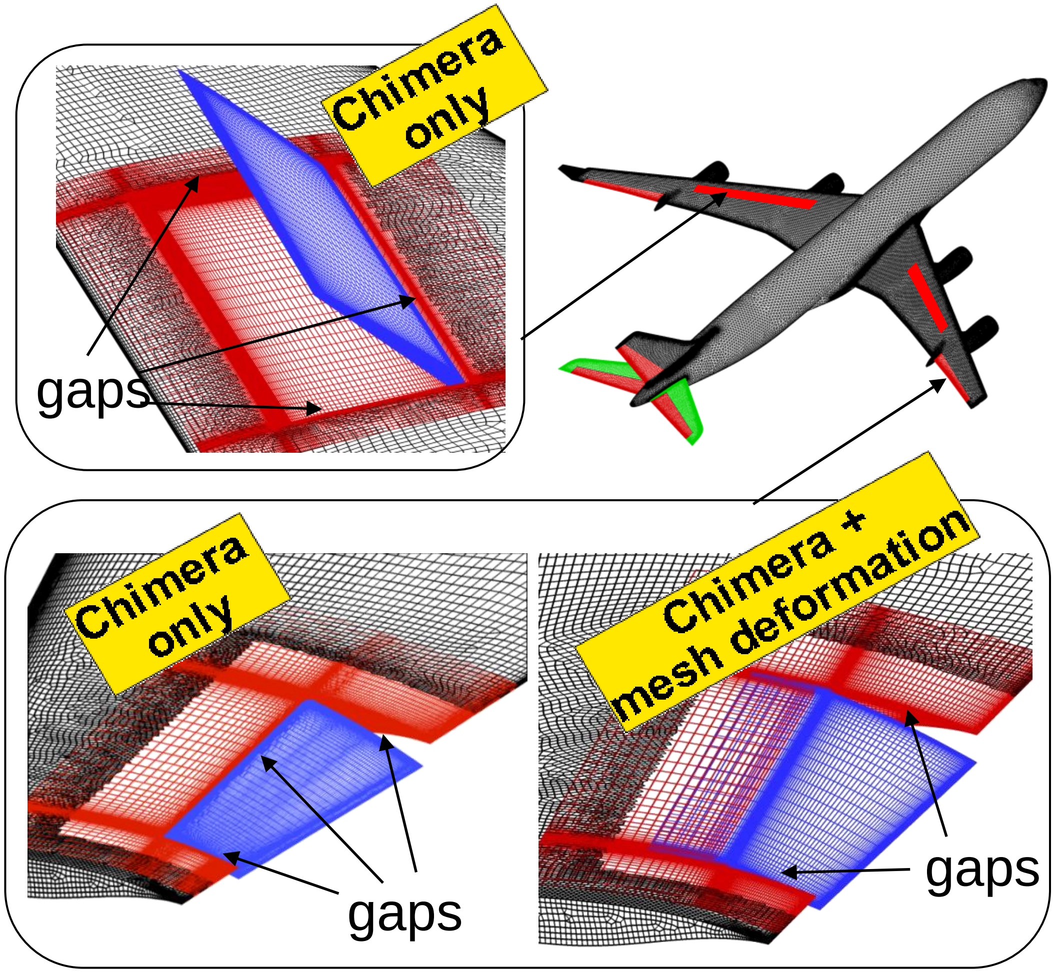




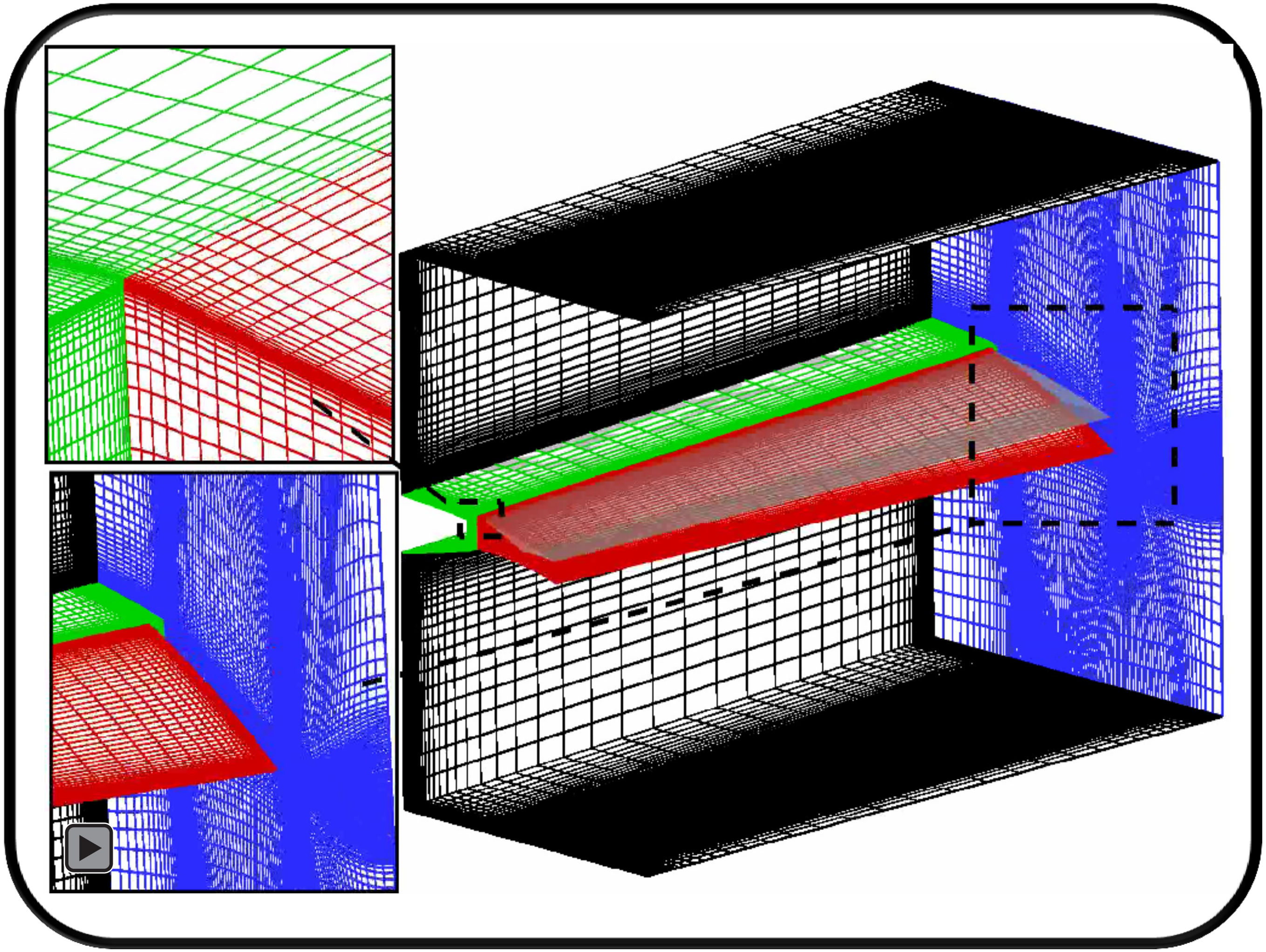
* HOST= Comprehensive analysis codes

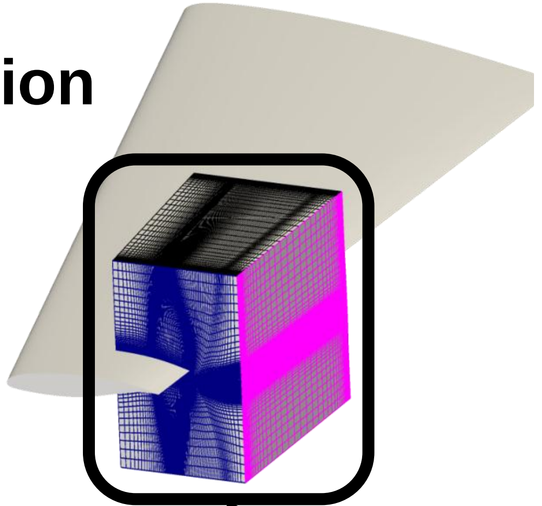
Control Surface (CS) Motions

- Meshing & sim. of configs. with **statically deflected CS** is standard application
- Though it still challenging consideration of **moving CS** becomes more important (e.g. analysis of maneuver loads & effectiveness of gust load alleviation systems)
- Main issue: Gap handling
  2 Approaches:
  - Chimera-only: Rotating Chimera block
  - Chimera+Mesh defo.: Fixed Chimera block (seems most promising)



Control Surface Motions:
Overset Grid Technology + Mesh Deformation

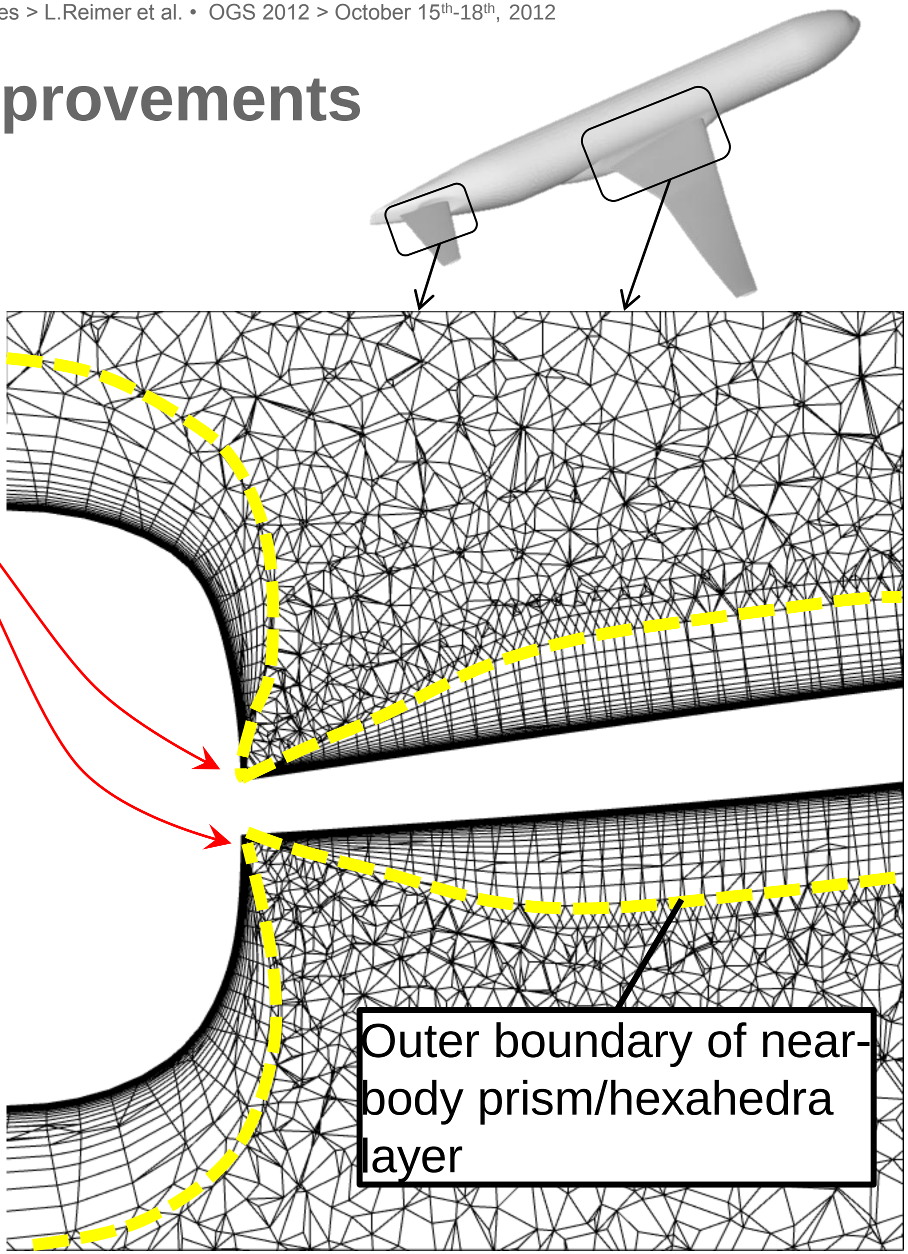




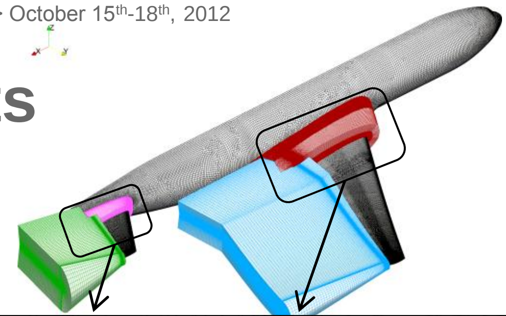
Mesh defo. only applied to Chimera block containing the aileron

Local Discretisation Improvements
Example from DPW-4

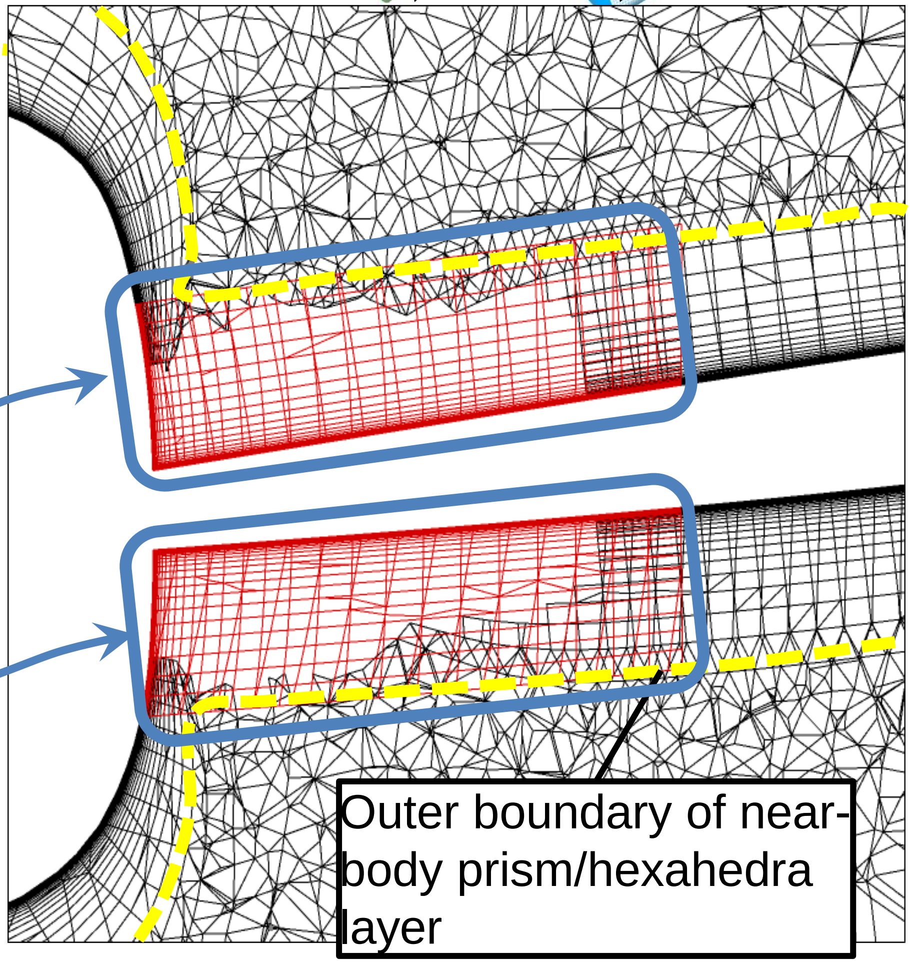
- Boundary layer in wing/HTP-fuselage junction of inappropriate quality
- Flow separations might not be detected at all or are metric driven



Local Discretisation Improvements
Example from DPW-4

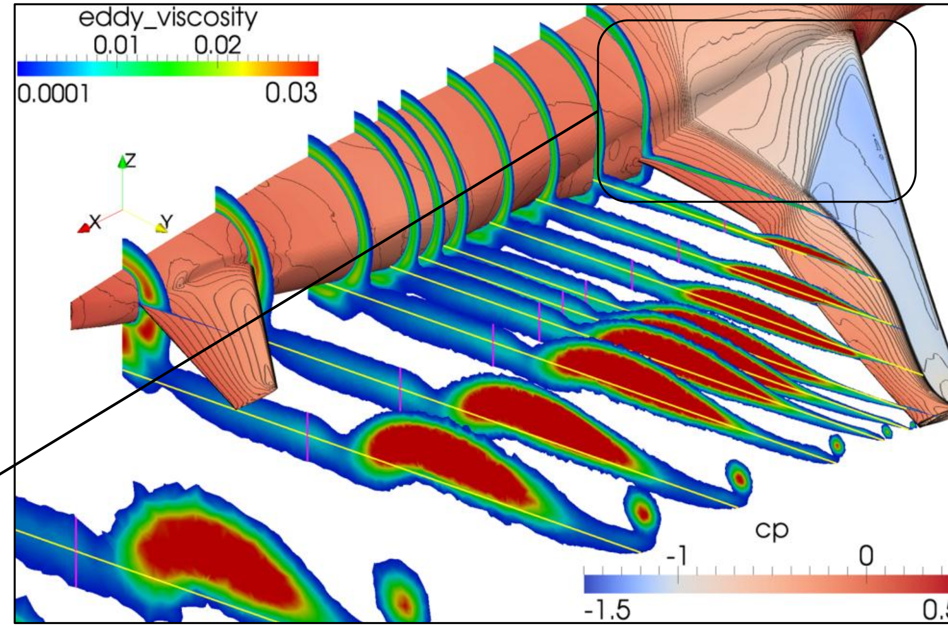


- ~~Boundary layer in wing/HTP-fuselage junction of inappropriate quality~~
- ~~Flow separations might not be detected at all or are metric driven~~
- Discretisation can be improved locally by inserting a structure Chimera grid

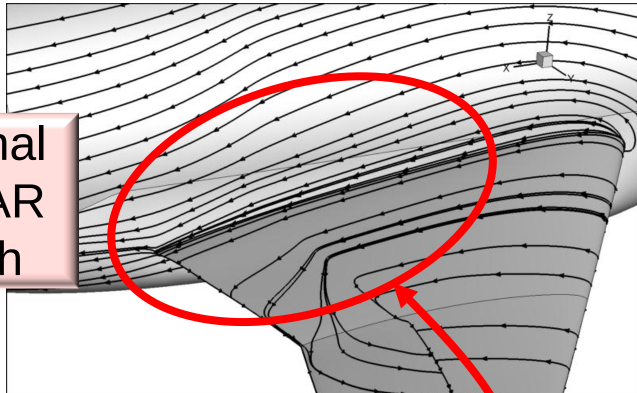


Local Discretisation Improvements

Example from DPW-4

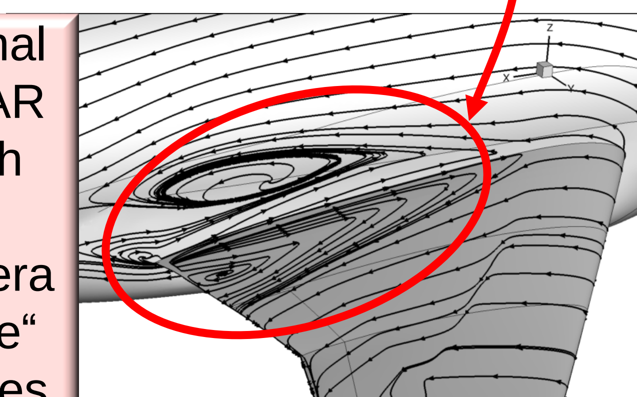


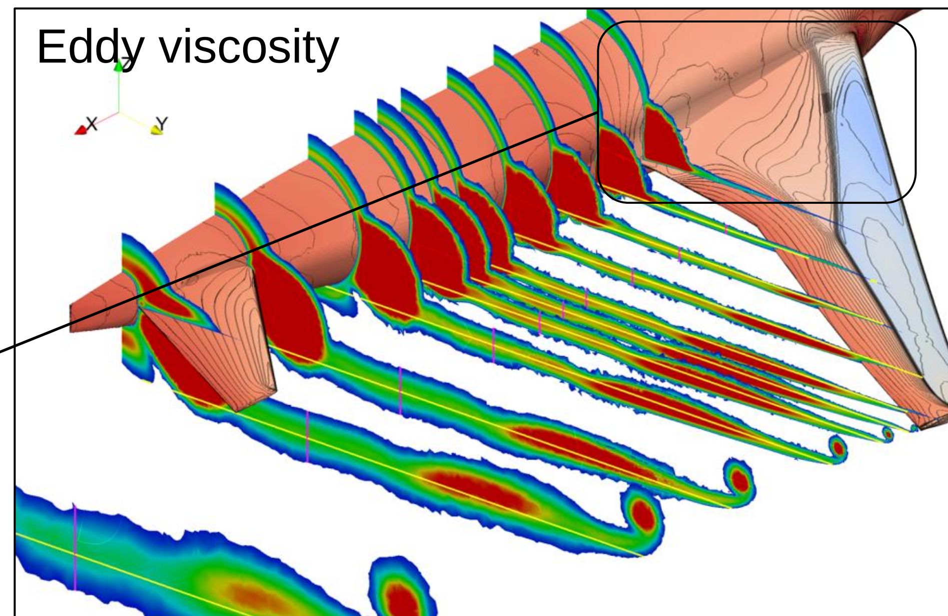
Original SOLAR mesh



streamlines

Original SOLAR mesh + Chimera „glove“ meshes

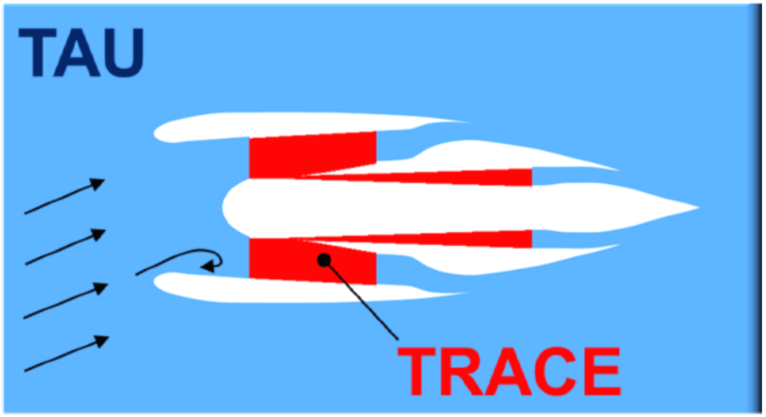


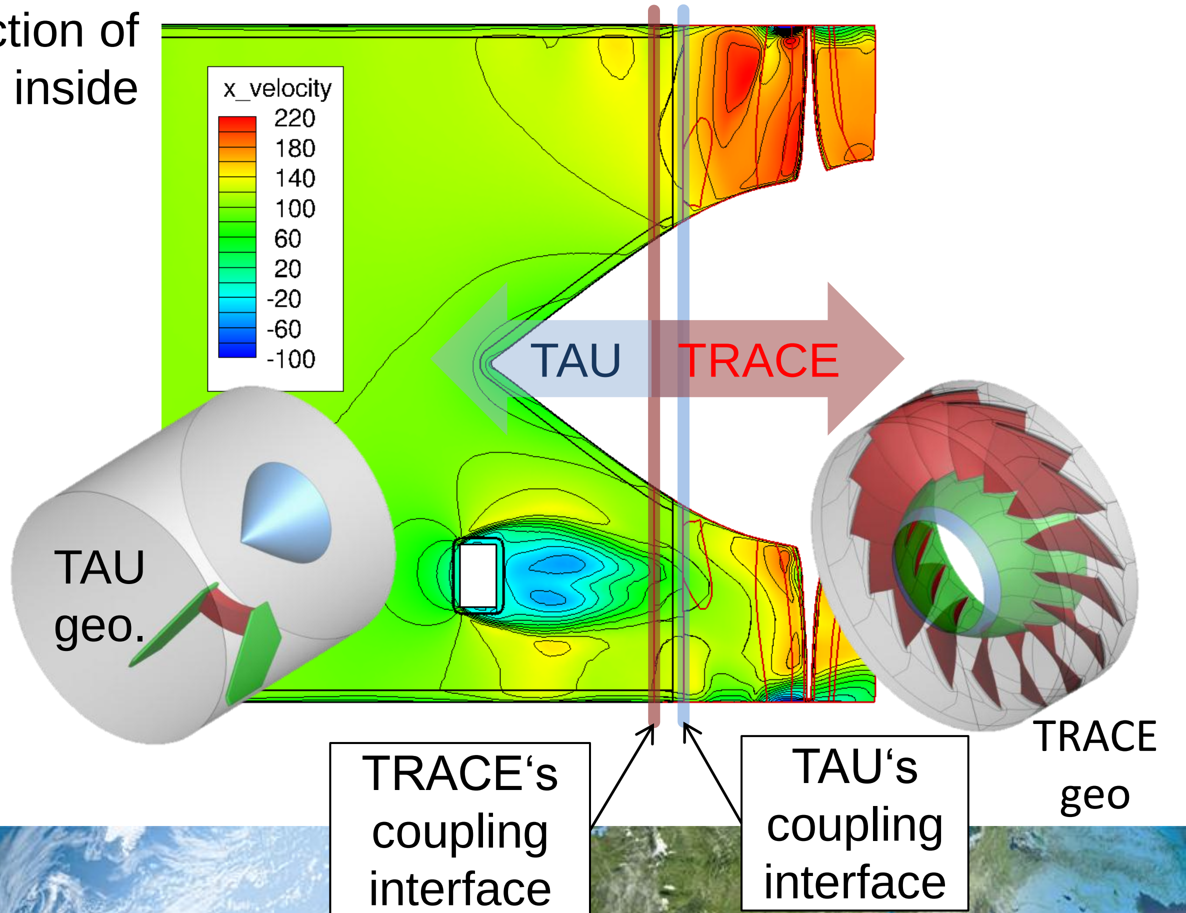


DLR

Code-to-Code Coupling: **TAU-TRACE**

- **Objective**: Flow simulation of a stalling nacelle including entry of the separated flow into the engine fan
- Requires accurate flow prediction of both external flow and flow inside engine fan
- **TRACE**:
  - DLR‘s turbomachinery CFD code
  - Multi-block-structured
  - cell-centered code (TAU: node-centered)
- Coupling controlled by socket communication layer
- Spatial coupling with Chimera





Code-to-Code Coupling:
TAU-Cartesian TAU

Problem: 2nd order spatial accuracy too dissipative for accurate computation of convection of gusts or wake vortices

Solution: Coupling of higher-order Cartesian solver (CTAU) to 2nd order solver (TAU)

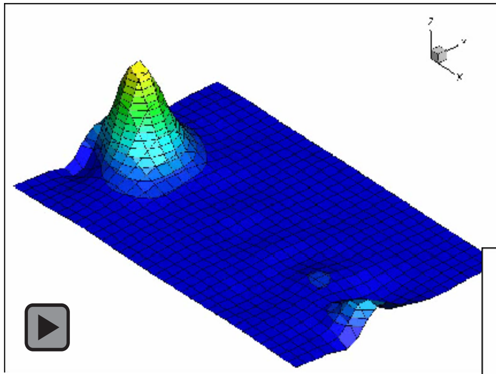
Cartesian TAU:
- ≥ 4th order spatially accurate (Pade scheme)
- very coarse Cartesian meshes, easy to generate

Conventional TAU:
- 2nd order spatially accurate
- fine body-fitted hybrid meshes

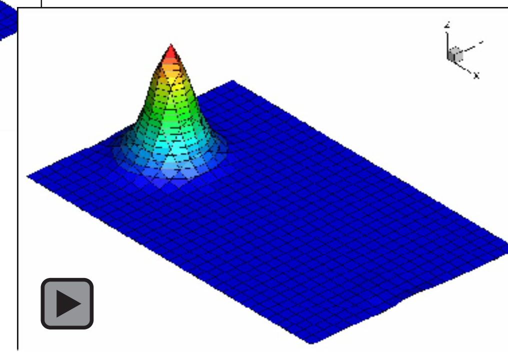
Coupling: overset grid interpolation

Example: Ehrenfried vortex

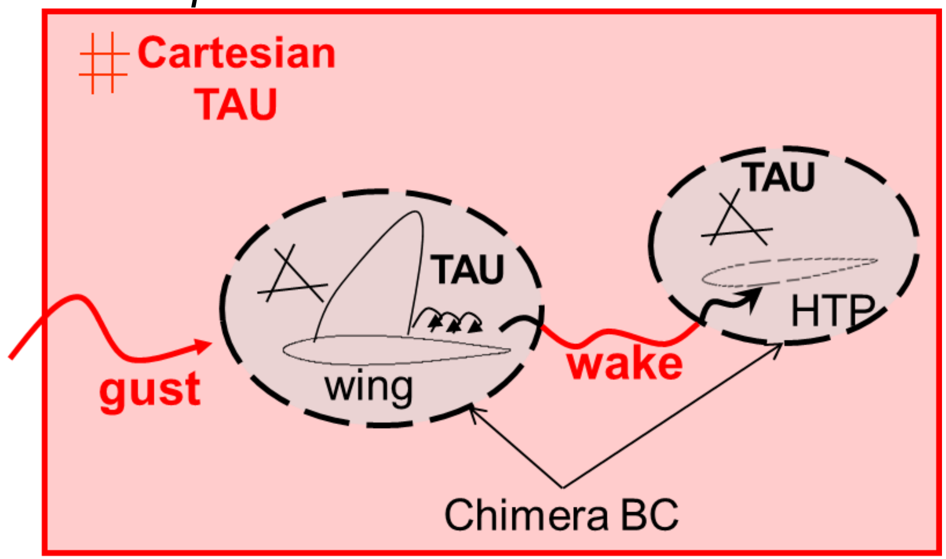
2nd order central



4th order Pade



Concept:



Conclusions

- DLR's CFD solvers are very mature, feature standard Chimera capabilities and are thus applicable to wide range of industrially-relevant configurations that need Chimera
- Our current major problem:
  - Too many manual operations needed to setup Chimera cases
  - Lack of toolkits like CGT, etc., at DLR
  - High demand for a more „automated" Chimera case setup process
- Since there is now a fast growing spectrum of applications that rely on the Chimera technique (Digital-X project: -> virtual flight testing), we currently increase our effort to bring forward our Chimera capabilities (e.g. overlap optimization, overlap adaptation, further development of CTAU solver, …)